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# INVESTIGATION OF FACTORS RELATED TO RUTTING OF BITUMINOUS PAVEMENT



## MONTANA DEPARTMENT OF HIGHWAYS

by

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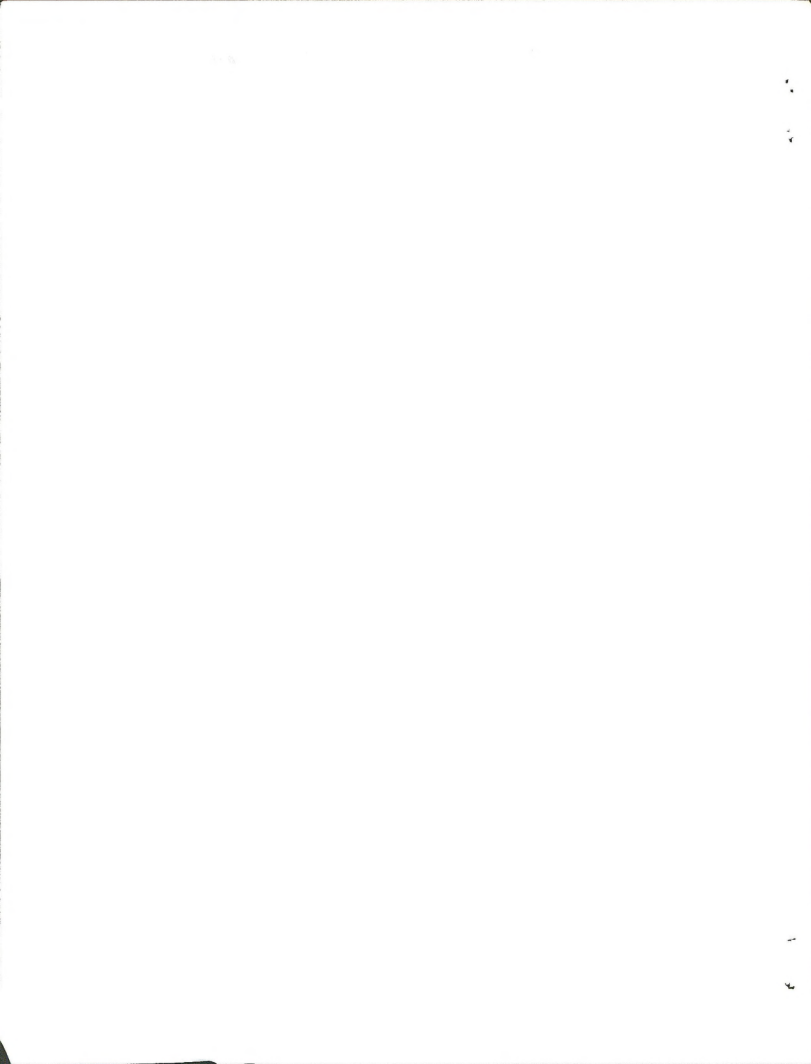
MATERIALS BUREAU

INVESTIGATION OF FACTORS RELATED TO  
RUTTING OF BITUMINOUS AGGREGATE MIXES

by

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November 1987

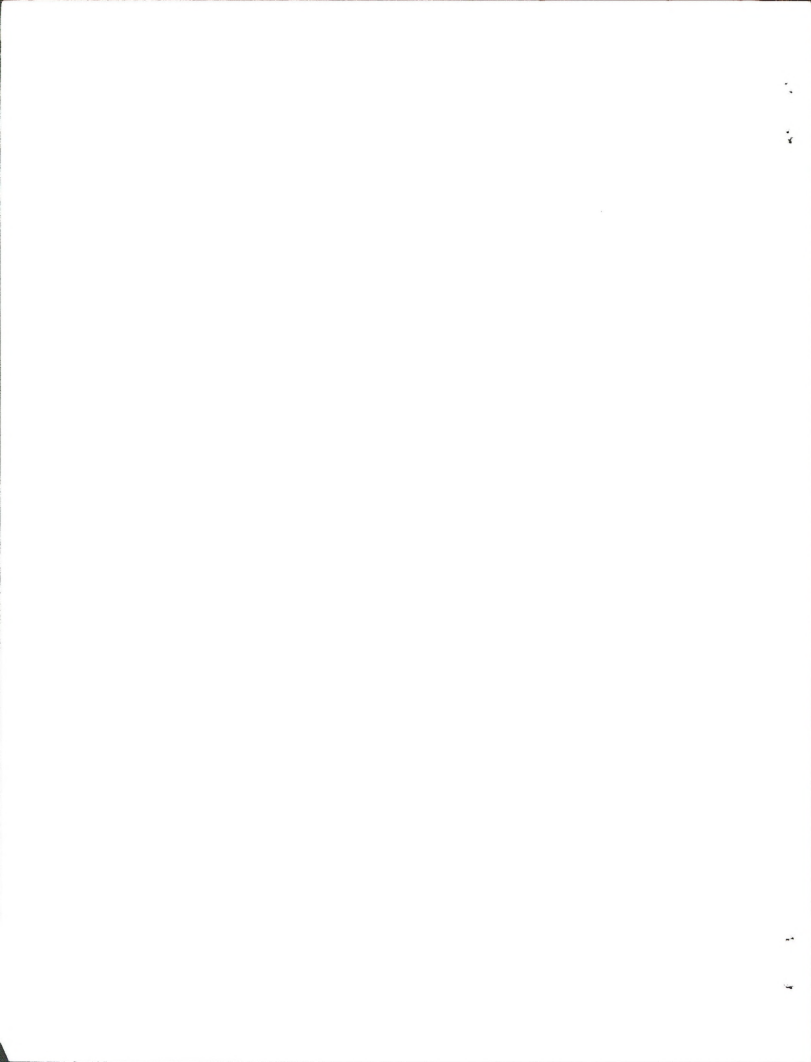


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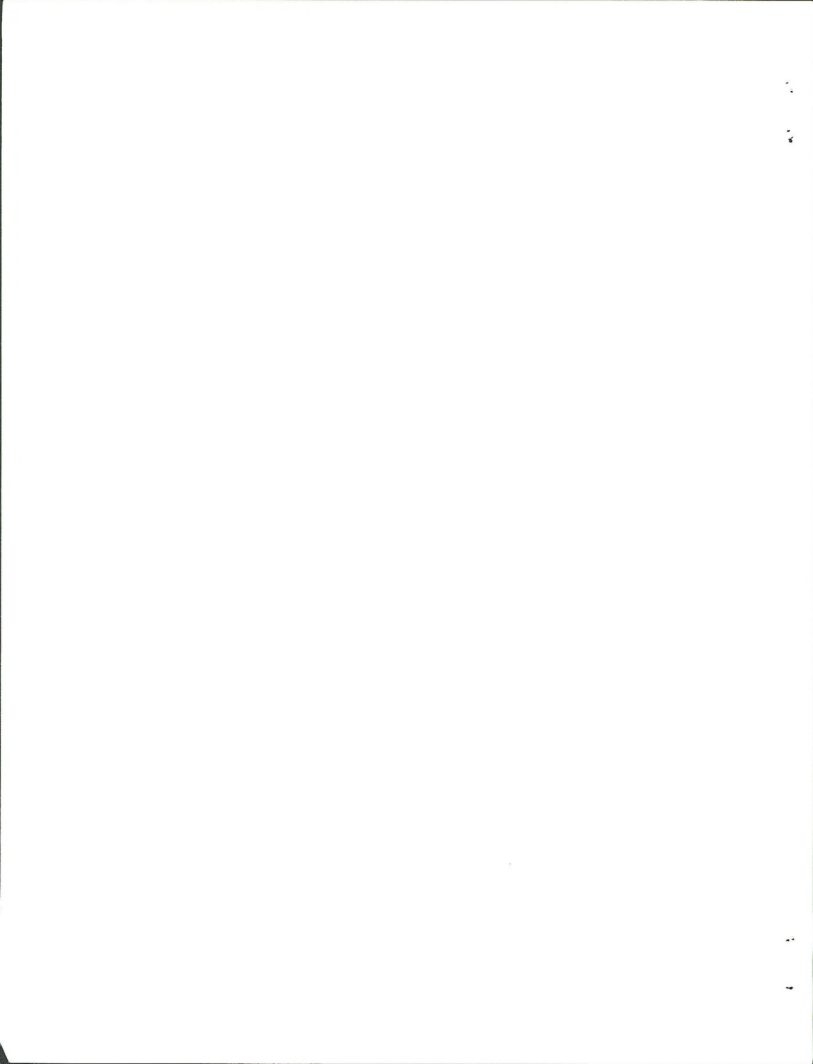
#### Acknowledgments

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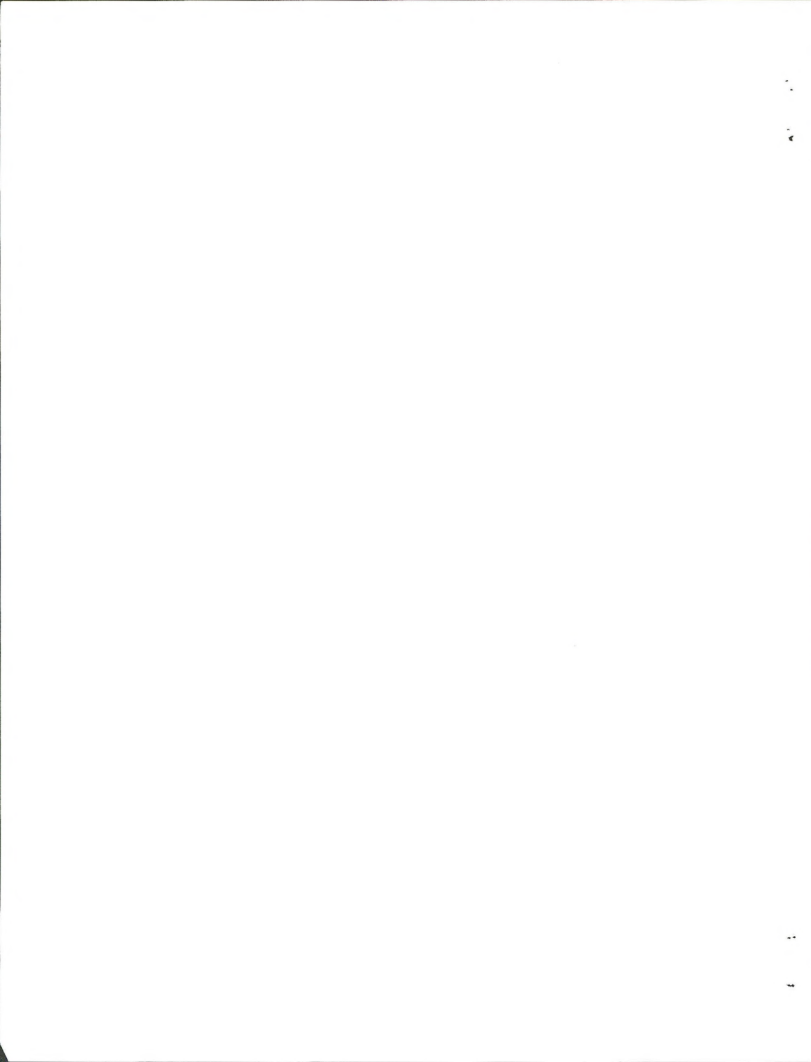
# CONTENTS

	<u>Page</u>
CONTENTS .....	iii
LIST OF FIGURES .....	iv
LIST OF TABLES .....	v
INTRODUCTION .....	1
INVESTIGATION SEQUENCE .....	2
A. Gradation .....	2
B. Asphalt Additives .....	4
C. Tensile Stress .....	4
D. Creep Testing .....	5
E. Binder Properties .....	5
F. Data Handling .....	5
INTERPRETATION OF TABLES .....	5
50 Blow Compaction Results for Gradations 1-8 .....	6
50 Blow Compaction Results for Gradations 1A-8A .....	7
75 Blow Compaction Results for Gradations 1-8 .....	8
75 Blow Compaction Results for Gradations 1A-8A .....	9
Average Data .....	10
50 Blow Compaction Results with Asphalt Additives .....	17
75 Blow Compaction Results with Asphalt Additives .....	18
50 Blow Marshall Data with Aggregate Source II .....	19
75 Blow Marshall Data with Aggregate Source II .....	21
ABSON TEST RESULTS .....	22
Marshall Stability .....	23-24
Gradations 1, 3 and 6 with additives .....	25-26
Tensile Strength .....	27
Dry Tensile Strength with Additives .....	28-29
Vacuum Saturated Tensile Strength with Additives .....	30-31
SUMMARY OF TENSILE STRENGTH TEST RESULTS .....	32
CREEP COMPLIANCE .....	33-37
CREEP COMPLIANCE TEST RESULTS WITH ADDITIVES .....	38-39
CONCLUSIONS .....	40
RECOMMENDATIONS .....	41



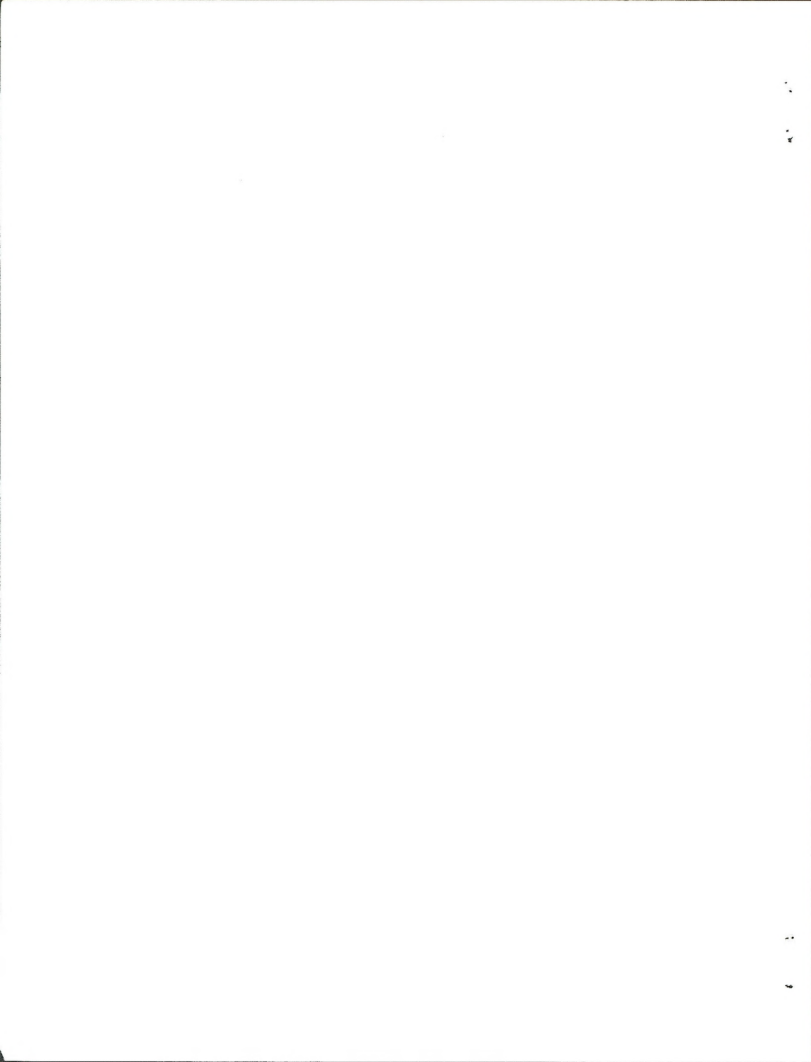
## LIST OF FIGURES

NO.	TITLE	PAGE
A.	GRADATIONS 1 THROUGH 4 .....	3B
B.	GRADATIONS 5 AND 6 .....	5
C.	GRADATIONS 7 AND 8 .....	6
1.	MARSHALL STABILITY (50 AND 75 BLOW) GRADATIONS 1-8 ...	23
2.	MARSHALL STABILITY (50 AND 75 BLOW) GRADATIONS 1A-8A .	24
3.	MARSHALL STABILITY (ADDITIVES) 50 BLOW .....	25
4.	MARSHALL STABILITY (ADDITIVES) 75 BLOW .....	26
5.	DRY AND VACUUM SATURATED TENSILE STRENGTH (50 AND 75 BLOW)	27
6.	DRY TENSILE STRENGTH (ADDITIVES) 50 BLOW .....	28
7.	DRY TENSILE STRENGTH (ADDITIVES) 75 BLOW .....	29
8.	VACUUM SATURATED TENSILE STRENGTH (ADDITIVES) 50 BLOW	30
9.	VACUUM SATURATED TENSILE STRENGTH (ADDITIVES) 75 BLOW	31
10.	CREEP COMPLIANCE TEST DATA (GRADATIONS 1-8) .....	34
11.	CREEP COMPLIANCE TEST DATA (GRADATIONS 1A-8A) .....	35
12.	CREEP COMPLIANCE NO ADDITIVE 50 BLOW .....	36
13.	CREEP COMPLIANCE NO ADDITIVE 75 BLOW .....	37
14.	CREEP COMPLIANCE WITH ADDITIVES 50 BLOW .....	38
15.	CREEP COMPLIANCE WITH ADDITIVES 75 BLOW .....	39



# LIST OF TABLES

<u>NO.</u>	<u>TITLE</u>	<u>PAGE</u>
1.	MARSHALL DATA - 50 BLOW GRADATIONS 1-8 .....	6
2.	MARSHALL DATA - 50 BLOW GRADATIONS 1A-8A .....	7
3.	MARSHALL DATA - 75 BLOW GRADATIONS 1-8 .....	8
4.	MARSHALL DATA - 75 BLOW GRADATIONS 1A-8A .....	11
5.	AVERAGE RESULTS .....	12
6.	MARSHALL DATA - 50 BLOW GRADATIONS 1-8 .....	13
7.	MARSHALL DATA - 50 BLOW GRADATIONS 1A-8A .....	14
8.	MARSHALL DATA - 75 BLOW GRADATIONS 1-8 .....	15
9.	MARSHALL DATA - 75 BLOW GRADATIONS 1A-8A .....	16
10.	MARSHALL DATA - 50 BLOW (ADDITIVES) .....	17
11.	MARSHALL DATA - 75 BLOW (ADDITIVES) .....	18
12.	50 BLOW MARSHALL DATA WITH AGGREGATE SOURCE II .....	20
13.	75 BLOW MARSHALL DATA WITH AGGREGATE SOURCE II .....	21
14.	ORIGINAL ASPHALT PROPERTIES .....	22
15.	EXTRACTED ASPHALT PROPERTIES .....	22
16.	SUMMARY OF TENSILE STRENGTH DATA .....	32

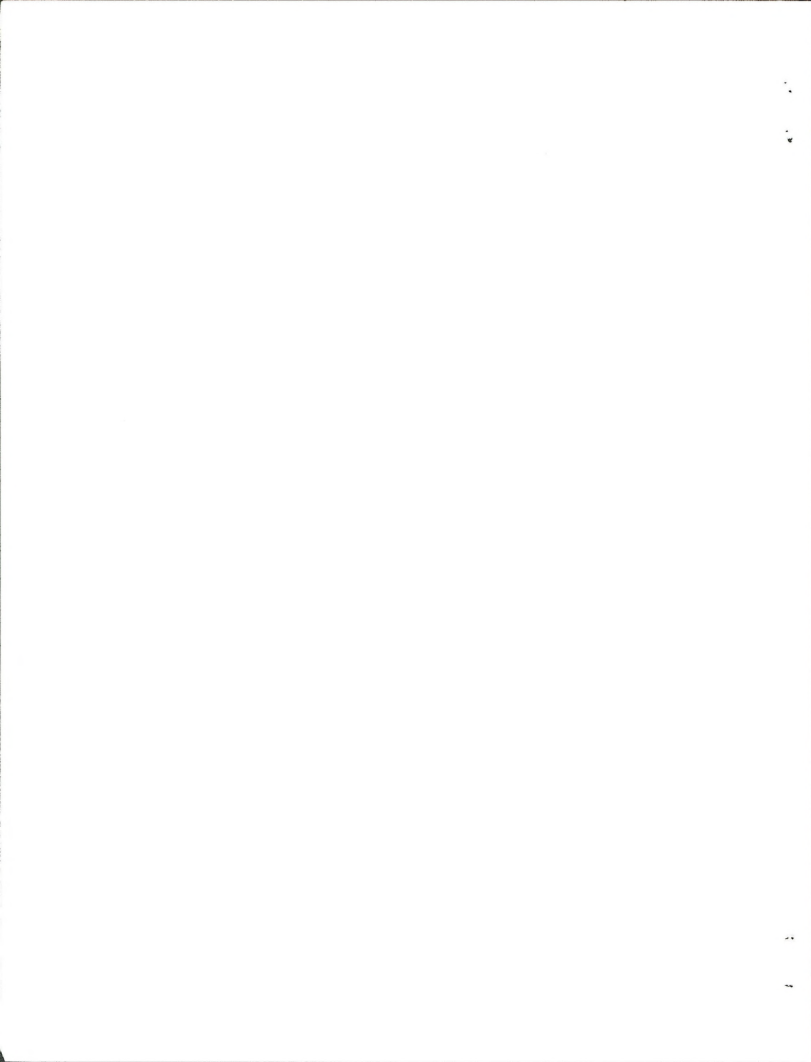


## INTRODUCTION

Soon after 1980, wheelpath rutting in asphalt pavements came to be recognized as a problem confronting the Montana Department of Highways. The overall picture became more sharply focused by 1982, and various efforts were initiated within the Department at that time to address this problem.

By 1982, it had also become clear that the rutting was not limited exclusively to older pavements, but was also occurring in a significant portion of the newer pavements, both overlays and new construction. To address this problem a number of improvements were implemented.

- A. Changes were made in aggregate gradations within the asphalt mixtures. Particular gradations produce mixtures that when compacted have fewer air voids, and thus greater density. These gradations also produce mixtures that when compacted have higher Marshall stabilities. Both higher densities and higher Marshall stability values are characteristic of pavements which better resist wheelpath rutting.
- B. The required fracture of the large aggregate particles was increased to 70%. Sharp corners on aggregate particles produce pavements which resist deformation after repeated loadings much better than typically smooth and rounded riverbed gravels.
- C. The control of asphalt mix production was increased through the introduction of statistical quality control methods. Contractors were financially rewarded or penalized based on how well they adhered to the construction specifications for the pavement.
- D. The specification for compaction was increased from 90% of Marshall density to 95% of Marshall density.
- E. The quality control during construction was also improved by the acquisition of sixteen test trailers to monitor bituminous mixtures as they were produced. With sophisticated, up-to-date equipment, information such as aggregate gradings, Marshall data and percent asphalt became immediately available to the field personnel.
- F. The asphalt plant operating temperature was raised to produce a mix using asphalt within a temperature viscosity range of  $170 \pm 20$  centistokes. This higher temperature slightly hardened the asphalt and facilitated compaction.
- G. High quality burner fuels used for heating the plant were specified for the first time. Low quality fuels are incompletely burned and contaminate the mixture. As contaminants, they increase the susceptibility of the mixture to stripping, soften the asphalt, and are generally detrimental.
- H. The addition of hydrated lime to the bituminous mixture was required more frequently. Adding hydrated lime to the bituminous mixture, at a rate of 1½% by weight of aggregate, has often proven to be beneficial. Hydrated



lime is known to harden asphaltic mixtures. It sometimes reduces "striping," and it causes some other mixture changes, not fully understood, that inhibit rutting. The introduction of hydrated lime into a bituminous mixture typically increases Marshall stability by 300 pounds.

- I. A harder, 85-100 penetration grade asphalt was specified for the first time for nearly all applications, including both new construction and overlays. This harder grade of asphalt resists softening much better when pavements are subjected to hot summer weather.

Initially, these changes were added to selected current projects, to assess their impact. The program was expanded and by 1985 almost all Grade B plant mix surfacing was constructed using these new specifications.

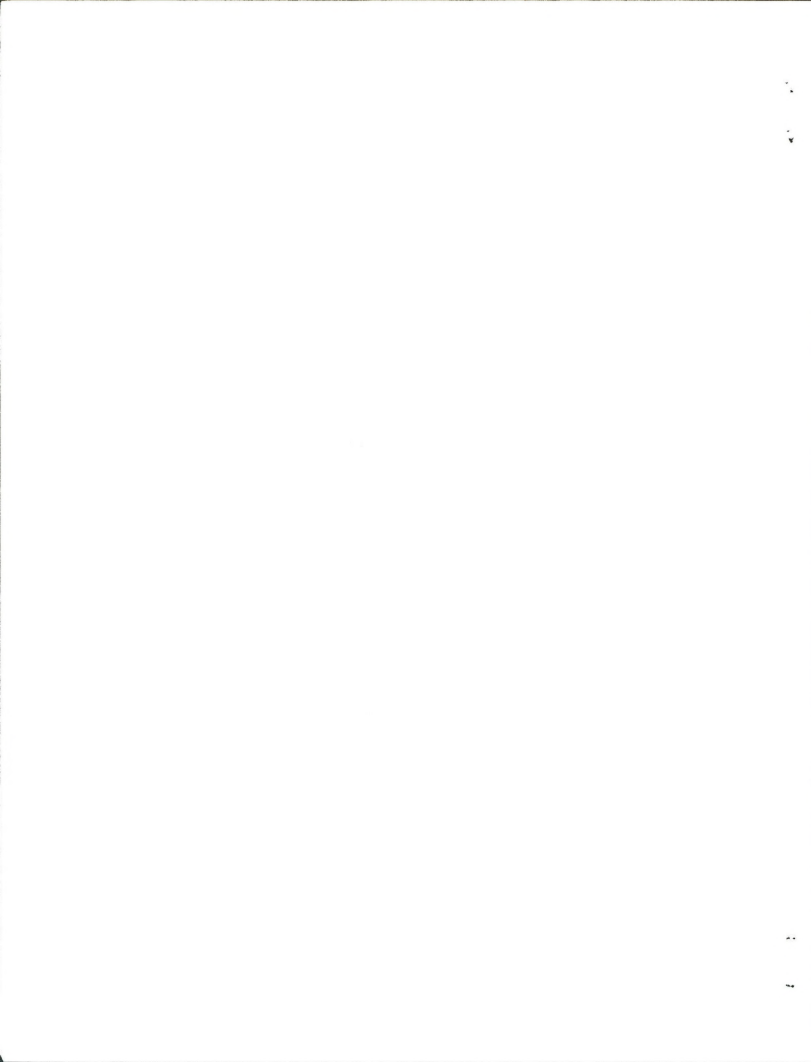
Although these anti-rutting specifications reduced rutting, reports from the district offices indicated that the problem of pavement rutting was still occurring in some of the newest pavements.

Starting in 1986, the Materials Bureau tested several bituminous plant mixtures to develop formulations for rut resistant bituminous pavements. The intent of this investigation was to develop supplemental design criteria and construction specifications to eliminate or reduce rutting of future bituminous pavements. The initial variable investigated was aggregate gradations. After generating data from comparing the effects of gradation on bituminous mixture properties, we extended our work to the evaluation of asphalt additives. Grading were selected for use in secondary trial testing. In these tests, the asphalt additive was changed as a controlled variable.

### Investigation Sequence

#### A. Gradation

To determine the effects of a range of alternative aggregate gradations on the bituminous mix design properties, Marshall specimens containing sixteen different gradations were produced. The same aggregate source and asphalt were utilized and all samples were tested in accordance with the Marshall method. Exxon 85/100 penetration grade asphalt cement was used as the binder throughout the test series. The selected aggregate source was a Yellowstone River aggregate from a location near Laurel, Montana, pit lab Nos. 584279-80 and 606045-53. This source was chosen because earlier Marshall tests using this same source has typically yielded stabilities of 1400 pounds. This is lower than a desired stability of 2000 pounds. The other aggregate and mixture characteristics were excellent, which provided an opportunity to isolate Marshall stability and mixture properties to study. Experimenting with a source aggregate that produced marginal Marshall stability, using specification gradations, was deliberate. Alternative gradings would exhibit their potential for improvement of bituminous mixture if Marshall stability was increased.

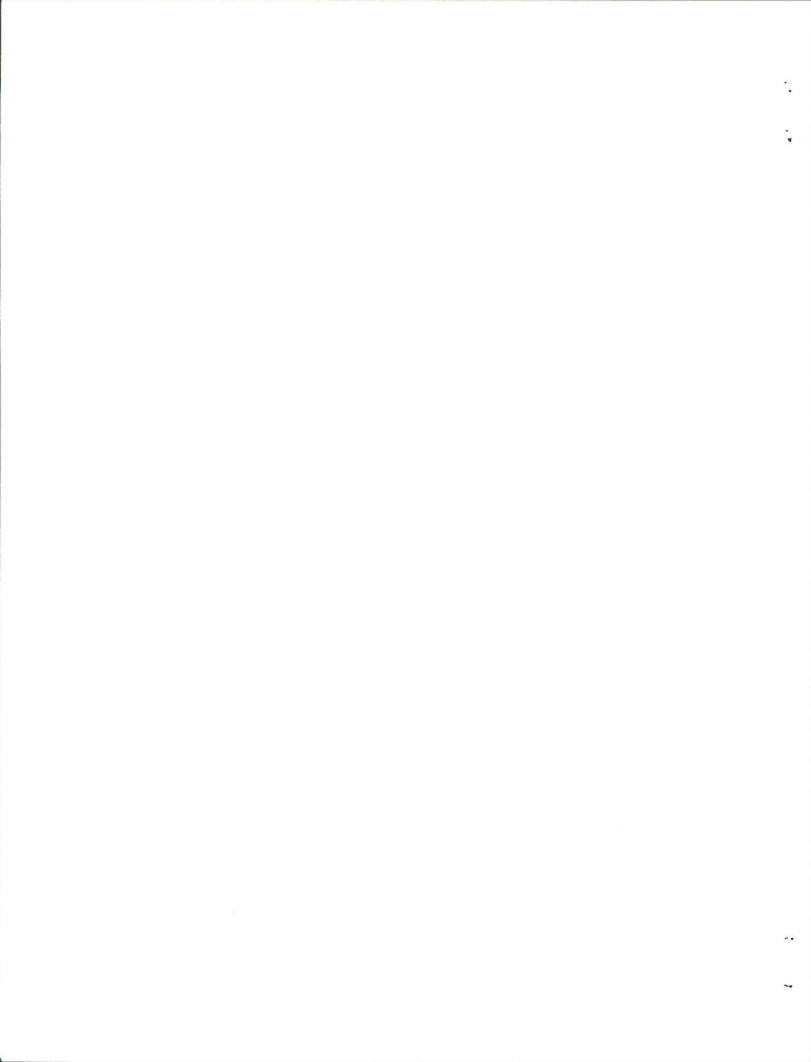


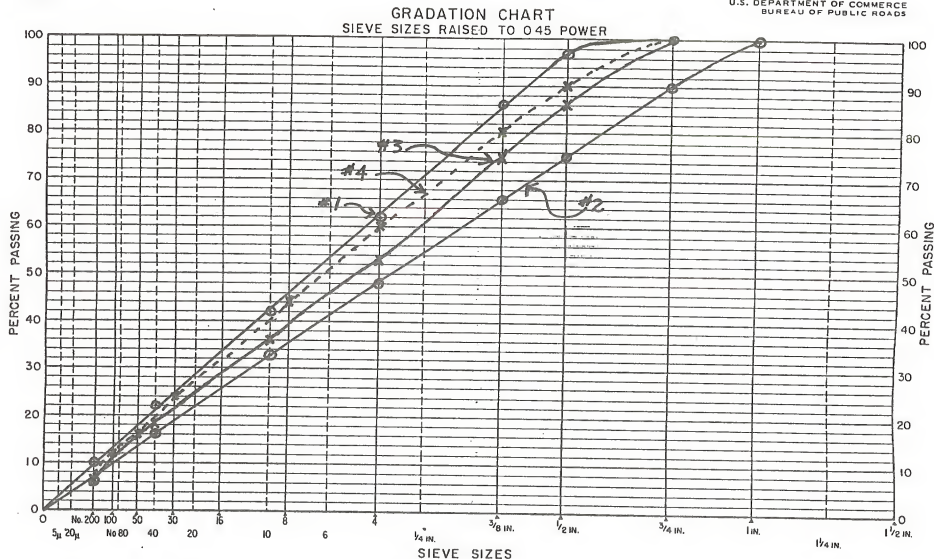
To verify that gradation was a significant factor in bituminous mixture properties, tests were repeated using a second aggregate source. If the Marshall data could be reproduced with a changed aggregate source, observations of the influence of aggregate grading would be supported. The source selected for this "repetition" was the Echart source located near Miles City. This source also had "good" aggregate properties, and was known to yield low Marshall stabilities.

The 16 aggregate gradations tested ranged from very fine to very coarse and included a full range of intermediate gradations. To plot the relative sizes of the aggregate particles used in the mixtures, we used Fuller curve 0.45 log paper. The property of the Fuller curve is that if a straight line is drawn through the X Y axis to any maximum aggregate size, using all of the intermediate points, would theoretically result in a completely voidless matrix of aggregate. Theoretically, deviations from the curve increase the voids in the aggregate by introducing a larger proportion of coarse or fine aggregate. Deviations to both sides of the line to partially nullify each other and produce an aggregate grading almost as dense as if it had followed the Fuller curve. Gradation No. 1 was based upon 97% passing the  $\frac{1}{2}$ -inch sieve with the remaining sieve percentages lying on Fuller's 0.45 power curve. Gradation No. 2 was based upon 90% passing the 3/4-inch sieve with the remaining sieve percentages also lying on its respective 0.45 power curve. Gradation No. 3 was representative of most gradations currently used in the Highway Department bituminous mixes. Gradation No. 4 was the Asphalt Institute's "4B" used by the Federal Aviation Agency for airport runways and jet parking aprons. Gradation No. 1 - No. 4 did not cross the Fuller curve. Gradation No. 5 through No. 8 deviated from the Fuller's maximum density 0.45 power curve as plotted on figures 1A - 1C. Gradation No. 5 and No. 6 crossed the Fuller curve at the 4M to 8M sieve sizes. Gradation No. 7 dropped below the Fuller curve on the 4M sieve size and Gradation No. 8 plotted above the Fuller curve on the 4M sieve size. Gradations 1A through 8A were the same as 1 through 8, except that the amount of 200 minus material was lowered to 4%.

Bituminous mixtures were produced using each of the alternative gradations. To achieve a common reference all of the bituminous mixture properties and requirements were initially determined for 3.5% air voids using 50 blow Marshall compaction. This level of air voids and compaction is commonly used by the Montana Department of Highways when developing mix designs. Tables 1 and 2 list data from the 50 blow Marshall specimens.

When the stability obtained using 50 blow Marshall compaction is inadequate for the projected traffic, Marshall compaction is often increased to 75 blows. This often increases stability although it may also result in a lower asphalt demand. Seventy-five blow compaction is also used by federal and state agencies for designing bituminous pavements. To determine how much the voids within the aggregate would be reduced by the increased compactive effort, sets of specimens for each gradation were therefore produced using 75 blow Marshall compaction. Tables 3 and 4 provide the Marshall data for the 16 gradations with the increased compactive effort.





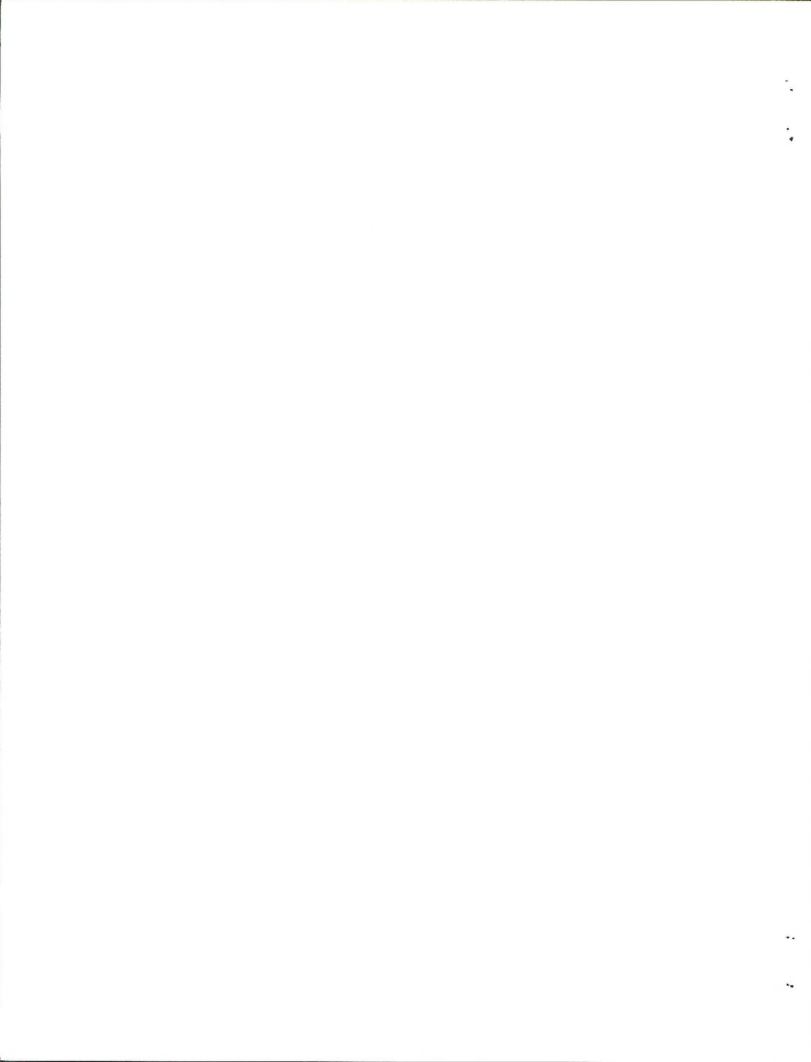
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COMPATIBLE SIEVE SIZES

Identification of gradations:

**LAUREL-MOSSMAIN RESEARCH**  
**GRADATIONS 1 THROUGH 4**

Sheet No.

Date



B. Asphalt Additives

Bituminous mixtures containing the additives Novophalt, Carbon Black, 3% Latex and AC 20R were tested. Selected aggregate gradings (Nos. 1, 3, and 6) previously analyzed for gradation were used for the additive testing. The same aggregate sources were used, so the test properties of the specimens with the additive could be directly compared to identical specimens without the additive.

C. Tensile Stress

Using Marshall and immersion compression data for each aggregate, grading, and asphalt additive, optimum mixtures for each alternative approach to mixture improvement were determined. These mixtures were evaluated for tensile strength in both dry and vacuum-saturated states. Tensile strength determinations are performed by loading a Marshall specimen vertically between two parallel horizontal plates using specified conditions of loading rate, temperature and saturation. The load is increased until the specimen yields and the stress is computed. The percentage change of strength of a saturated specimen, compared to the strength of a companion dry specimen, is expressed as the retained strength of the mixture. The actual loads at yield are also recorded.

D. Creep Testing

Creep testing was also done. Creep testing uses the same loading configuration as tensile strength testing but the load is constant and imposed over an extended period of time. The amount of deformation of the specimen is measured at timed intervals using controlled temperature and a constant load on the specimen. The values of deformation over time, obtained with the tested gradations and compactive effort, were compared. The gradations and mixtures that were most resistant to deformation after an extended static load were the most desirable.

E. Binder Properties

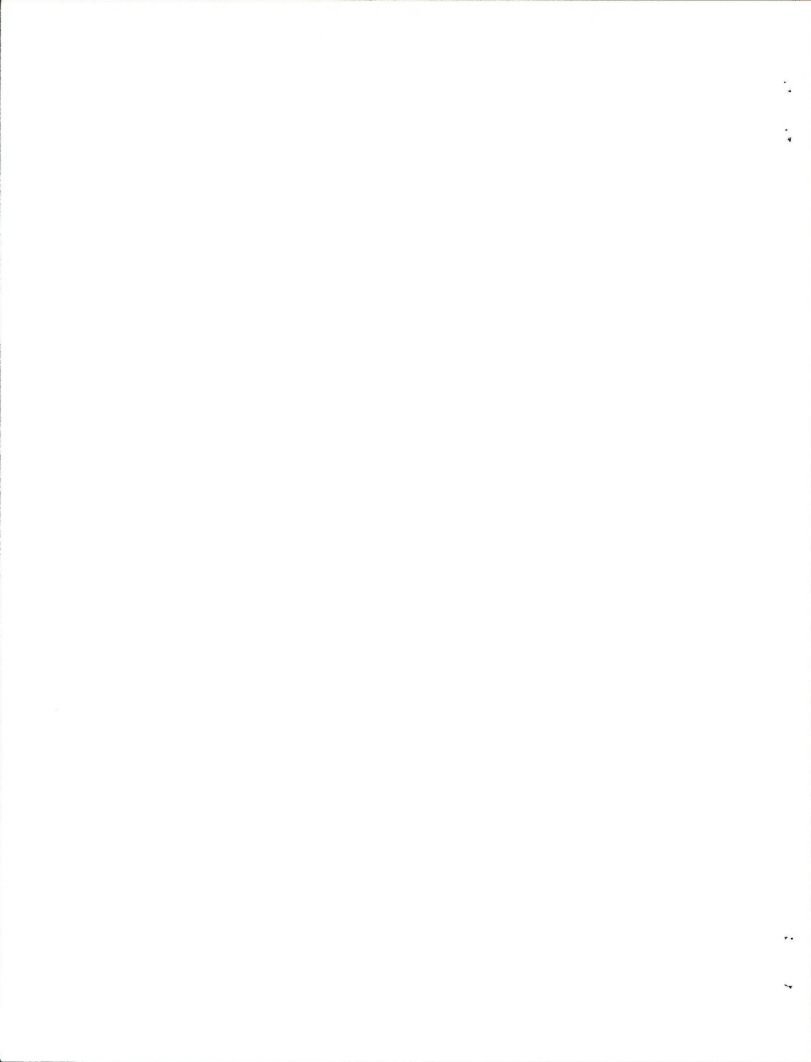
The physical properties of virgin asphalt and the asphalt with additives, before and after extraction, were determined. Tests included; penetration, ductility, viscosity, toughness and tenacity and softening point.

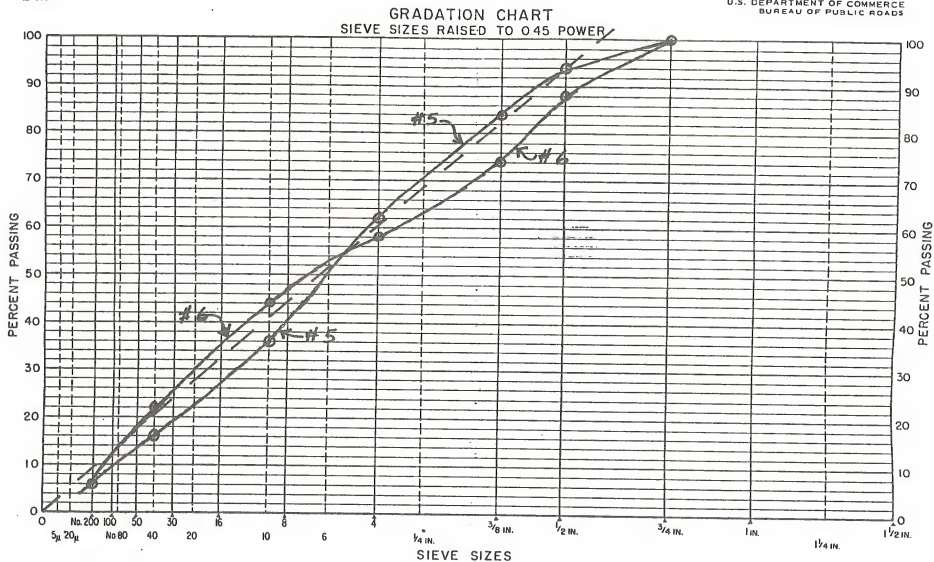
F. Data Handling

Data is arranged in several tables within the report to facilitate identification of significant property and data relationships.

As a supplement to tables, computer generated graphic displays of test information were produced. These graphs emphasized the comparisons of specific qualities of the bituminous mixtures.

So much data was generated we decided to present and analyze the data in the same sequence in which it was developed.





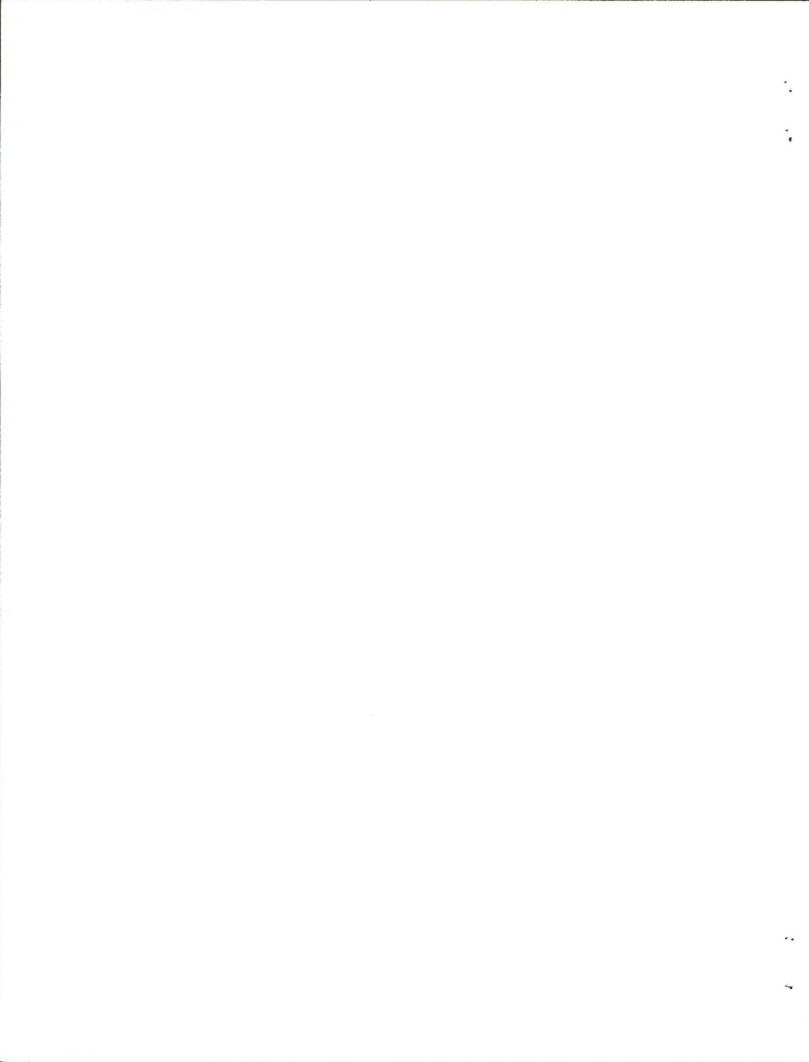
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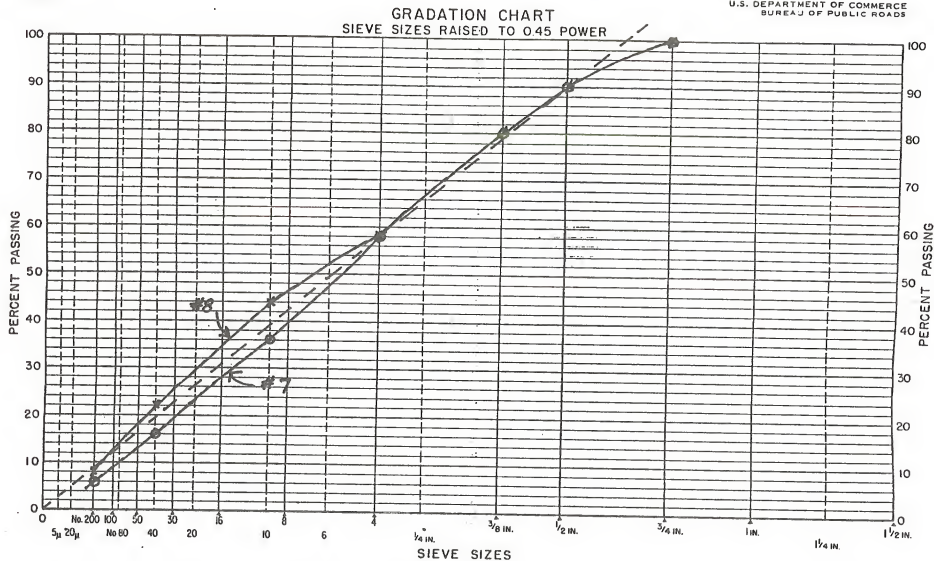
Identification of gradations:

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**GRADATIONS 5 AND 6**

Sheet No.

Date





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PRACTICE AND  
COMPATIBLE SIEVE SIZES

Identification of gradations:

**LAUREL-MOSSMAN RESEARCH**  
**GRADATIONS 7 AND 8**

Sheet No.

Date



DISCUSSION AND INTERPRETATION OF DATA  
IN TABLES 1-15

As we proceeded with this study, we sometimes realized a need for additional information which required more tests. Sometimes rearranging the existing data gave it a new emphasis.

With each table of data in this report, is a paragraph that briefly describes the most obvious behaviors or relationships that we recognized from that particular table. If, from these tables, we suspected other dependent relationships, we redisplayed the data or did additional testing to confirm or refute our theories.

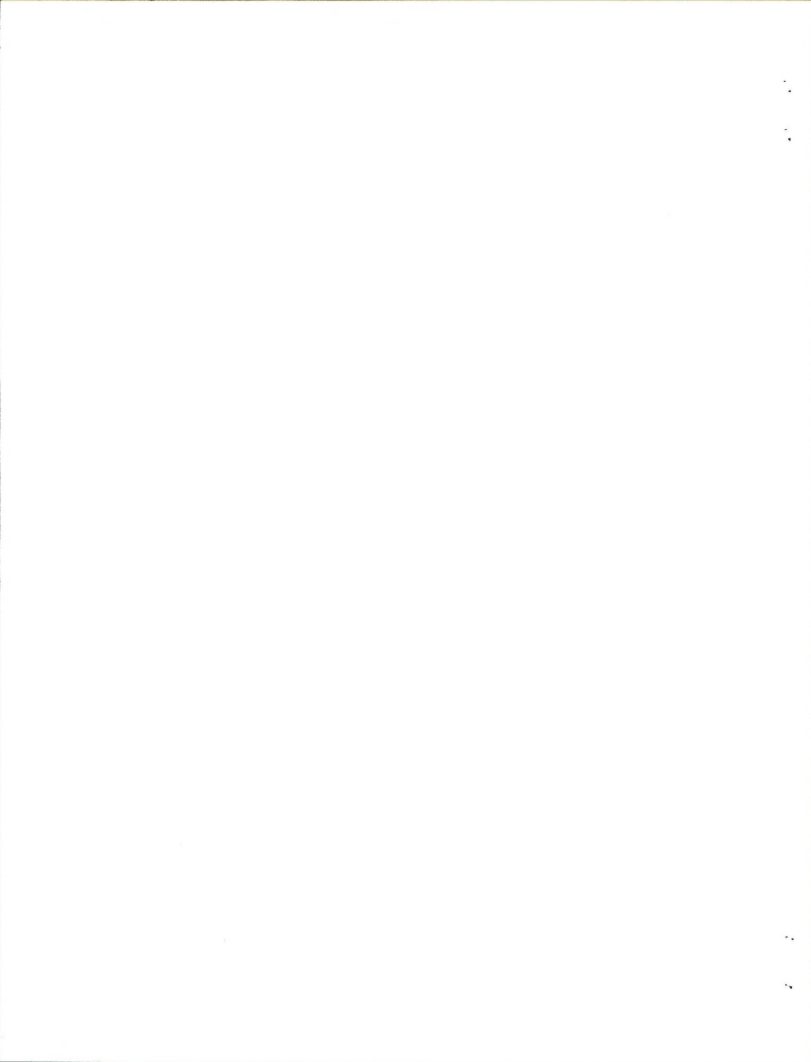


TABLE 1. Marshall Data Source 1  
(50 Blow)

Sieve Size	1	2	3	4**	5	6	7	8
1"		100						
3/4"	100	90	100	100	100	100	100	100
1/2"	97	75	86	90	94	88	90	90
3/8"	86	66	75	80	84	74	80	80
#4	62	48	53	60	62	58	58	58
#8				44				
#10	42	33	36		36	44	36	44
#30				24				
#40	22	16	18		16	22	16	22
#50				16				
#100				12				
#200	10	6	6	6	6	6	6	8
Asphalt Content	6.0	5.9	6.3	7.2	6.9	6.9	6.6	6.5
% Voids	3.6	3.5	3.5	3.5	3.5	3.5	3.7	3.5
Stability	1911	1565	1498	1596	1590	1615	1610	1811
Density	2.335	2.345	2.327	2.299	2.317	2.317	2.323	2.330
Flow	11	9	12	13	10	9	10	10
VMA	15.0	14.6	15.6	17.3	16.4	16.4	16.0	15.6
Imm. Comp. Ratio	55.9	66.5	63.1	55.1	56.9	56.2	93.0*	81.2*
Dry Strength	263.3	237.9	230.7	257.0	264.2	283.3	262.6	313.5
Wet Strength	147.2	158.3	145.6	141.6	150.4	159.2	244.3	254.7

\*Resampled aggregate

\*\*Asphalt Institute 4B Gradation using different sieves nest

#### Observations

This table shows Marshall properties of bituminous mixtures fabricated using the eight primary gradations that we initially tested.

Changes in gradation changed the asphalt content requirements. The percent of asphalt required to obtain approximately 3.5% voids ranged from 5.9% to 7.2%. Depending upon on the gradation, Marshall stabilities ranged from 1500 lb. to 1900 lbs. Gradation No. 1 had the highest stability, 1911 lbs.

The retained strength, determined by the Immersion Compression, was not significantly changed by differences in % AC or gradation of the aggregate. The improved retained strength of gradations 7 and 8 is attributed to resampling and obtaining higher quality aggregate. Note: Resampling was necessary since the first supply of aggregate was depleted before all test specimens were made.



TABLE 2. Marshall Data  
(50 Blow)

Sieve Size	1A	2A	3A	4A	5A	6A	7A	8A
1"		100						
3/4"	100	90	100	100	100	100	100	100
1/2"	97	75	86	90	94	88	90	90
3/8"	86	66	75	80	84	74	80	80
#4	62	48	53	60	62	58	58	58
#8				44				
#10	42	33	36		36	44	36	44
#30				24				
#40	22	16	18		16	22	16	22
#50				16				
#100				12				
#200	4	4	4	4	4	4	4	4
Asphalt Content	7.0	6.0	6.4	6.65	7.0	7.1	6.9	7.0
% Voids	3.5	3.4	3.6	3.5	3.5	3.6	3.5	3.5
Stability	1488	1707	1595	1893	1625	1438	1670	1800
Density	2.288	2.342	2.330	2.319	2.315	2.307	2.314	2.312
Flow	10	10	9	10	11	10	10	11
VMA	17.5	14.8	15.5	16.1	16.6	16.9	16.5	16.7
Imm. Comp. Ratio	92.9	93.2	75.1			92.0		
Dry Strength	202.1	198.9	210.8			227.5		
Wet Strength	187.8	185.4	158.3			209.2		

#### Observations

Eight bituminous mixtures were fabricated with the -200M reduced to 4% but with the same gradations in other sieve sizes as their counterparts on Table 1. In comparing Table 1 and Table 2 data we noted the following responses in the mixture.

For five of the gradations, reducing the -200M to 4% increased the asphalt demand slightly. With one gradation (No. 4A), asphalt demand actually decreased. The finer gradations 1 and 8 were more sensitive to changes in -200M; the reduction increased the asphalt demand by 1/2% to 1%. Marshall stabilities of all of the gradations were reduced an average of 400/pounds when the % -200M was reduced to 4%.



TABLE 3. Marshall Data  
(75 Blow)

Sieve Size	1	2	3	4	5	6	7	8
1"		100						
3/4"	100	90	100	100	100	100	100	100
1/2"	97	75	86	90	94	88	90	90
3/8"	86	66	75	80	84	74	80	80
#4	62	48	53	60	62	58	58	58
#8				44				
#10	42	33	36		36	44	36	44
#30				24				
#40	22	16	18		16	22	16	22
#50				16				
#100				12				
#200	10	6	6	6	6	6	6	8
Asphalt								
Content	5.75	5.3	5.90	6.70	6.0	6.0	6.2	5.90
% Voids	3.5	3.6	3.5	3.5	3.5	3.4	3.4	3.6
Stability	2219	1836	1750	1785	2089	2288	2004	2338
Density	2.350	2.359	2.342	2.319	2.346	2.350	2.343	2.348
Flow	10	9	9	9	9	9	9	9
VMA	14.3	13.6	14.7	16.2	14.7	14.5	14.9	15.3
Imm. Comp.								
Ratio	52.6	60.2	66.3	59.5	44.3	39.5	57.3	54.1
Dry Strength	322.2	241.9	241.1	231.5	228.3	245.8	218.0	242.6
Wet Strength	169.5	145.6	159.9	137.6	101.0	97.1	124.9	131.3

#### Observations

Seventy five blow compaction is sometimes used to increase the stability of bituminous mixtures without changing anything but the compactive effort. Table three data was produced to allow comparison of the eight selected gradations using seventy five blow compaction to fabricate bituminous mixtures.

A comparison of this data, 75-blow Marshall compaction to Table 1 using 50-blow Marshall compaction showed that asphalt demand decreased approximately 0.5% with the higher compaction. A minor exception was gradation 1, for which the asphalt demand was reduced 0.25% by the additional compaction. Expressed as an average behavior, stability increased 400 lbs. and VMA was reduced from 15.8% to 14.7%. Immersion compression was not affected by the lower % AC except when the % AC was reduced more than .7% to achieve voids; this occurred with gradations 5 and 6.



TABLE 4. Marshall Data  
(75 Blow)

Sieve Size	1A	2A	3A	4A	5A	6A	7A	8A
1"		100						
3/4"	100	90	100	100	100	100	100	100
1/2"	97	75	86	90	94	88	90	90
3/8"	86	66	75	80	84	74	80	80
#4	62	48	53	60	62	58	58	58
#8				44				
#10	42	33	36		36	44	36	44
#30				24				
#40	22	16	18		16	22	16	22
#50				16				
#100				12				
#200	4	4	4	4	4	4	4	4
Asphalt								
Content	6.25	5.50	5.90	6.45	6.5	6.5	6.5	6.4
% Voids	3.5	3.5	3.4	3.5	3.6	3.6	3.6	3.5
Stability	2031	1846	1858	1841	1711	1891	2098	1986
Density	2.324	2.356	2.349	2.326	2.328	2.326	2.328	2.332
Flow	9	9	9	11	8	9	10	9
VMA	15.7	13.9	14.5	15.7	15.7	15.8	15.7	15.5
Imm. Comp.								
Ratio	62.5	99.6	82.5		80.5			
Dry Strength	216.4	167.8	214.0		211.6			
Wet Strength	135.2	167.1	176.6		170.2			

#### Observations

This table is a supplement to Table 2 data. It shows the change of the properties of the bituminous mixtures containing 4% -200M when using additional compaction.

A comparison of this data for 75-blow Marshall compaction to Table 2 using 50-blow Marshall compaction showed asphalt demand decreased approximately 0.5% with the higher compaction. A minor exception was gradation 1, for which the asphalt demand was reduced 0.25% by the additional compaction. Expressed as average behavior, stability increased 400 lbs. and VMA was reduced from 16.4% to 15.5%.



TABLE 5. AVERAGE RESULTS

Properties	Table 1 (50 blow)	Table 2 (50 blow)	Table 3 (75 blow)	Table 4 (75 blow)
Asphalt Content	6.53	6.83	5.96	6.33
Stability	1631	1648	2037	1909
Density	2.325	2.316	2.347	2.332
Flow	10.3	10.2	9	9.2
V.M.A.	15.8	16.4	14.7	15.5
Immersion Compression	59.0*	88.3	54.7	81.3

Observations

This table was written to identify the average Marshall properties of bituminous mixtures using the primary gradations, gradations with 4% -200M, and these same gradations with 75 blow Marshall compaction.

For each series of gradations tested (1 through 8 and 1A through 8A), the 75 blow Marshall compaction produced higher densities and stabilities. The greatest improvement in stabilities was obtained from gradations which deviated from Fuller's 0.45 power curve. Lowering the amount of minus 200 material increased the average asphalt content requirement for both the 50 and 75 blow Marshall specimens increased approximately 0.3 percent.



TABLE 6. MARSHALL DATA  
(50 Blow)

Gradation	5.5%				6.0%				6.5%			
	Stability	Density	Voids	VMA	Stability	Density	Voids	VMA	Stability	Density	Voids	VMA
1	2000	2.303	5.9	15.8	1911	2.335	3.6	15.0	1872	2.348	2.0	15.0
2	1690	2.334	4.4	14.7	1534	2.348	3.2	14.6	1447	2.372	1.5	14.1
3	1213	2.307	5.7	15.7	1400	2.320	4.5	15.6	1563	2.330	2.9	15.6
4					1352	2.265	6.7	17.6	1378	2.282	5.4	17.4
5	1408	2.261	7.5	17.4	1398	2.277	6.3	17.2	1317	2.283	5.4	17.3
6	1283	2.274	7.2	16.9	1238	2.292	5.6	16.6	1575	2.313	4.2	16.2
7	1533	2.286	6.7	16.4	1508	2.292	5.8	16.6	1529	2.316	4.1	16.1
8	1725	2.301	6.1	15.9	1889	2.314	4.9	15.8	1811	2.330	3.5	15.6

#### Observations

This table was written to compare the voids and mixture properties of the 8 primary gradations at fixed percentages of asphalt using fifty blow Marshall compaction. It was observed that bituminous mixtures fabricated using different gradations could exhibit similar properties; for example gradations 4 and 5.

Some mixture gradations contain insufficient asphalt at 6% AC (e.g. gradations 3 and 6) while other gradations contain proper AC at 6% (e.g. gradations 1 and 2). The range of Marshall voids obtained was 3.2% to 6.7% with 50 blow compaction and 6.0% asphalt. Thus, gradation and voids relationships are complex.

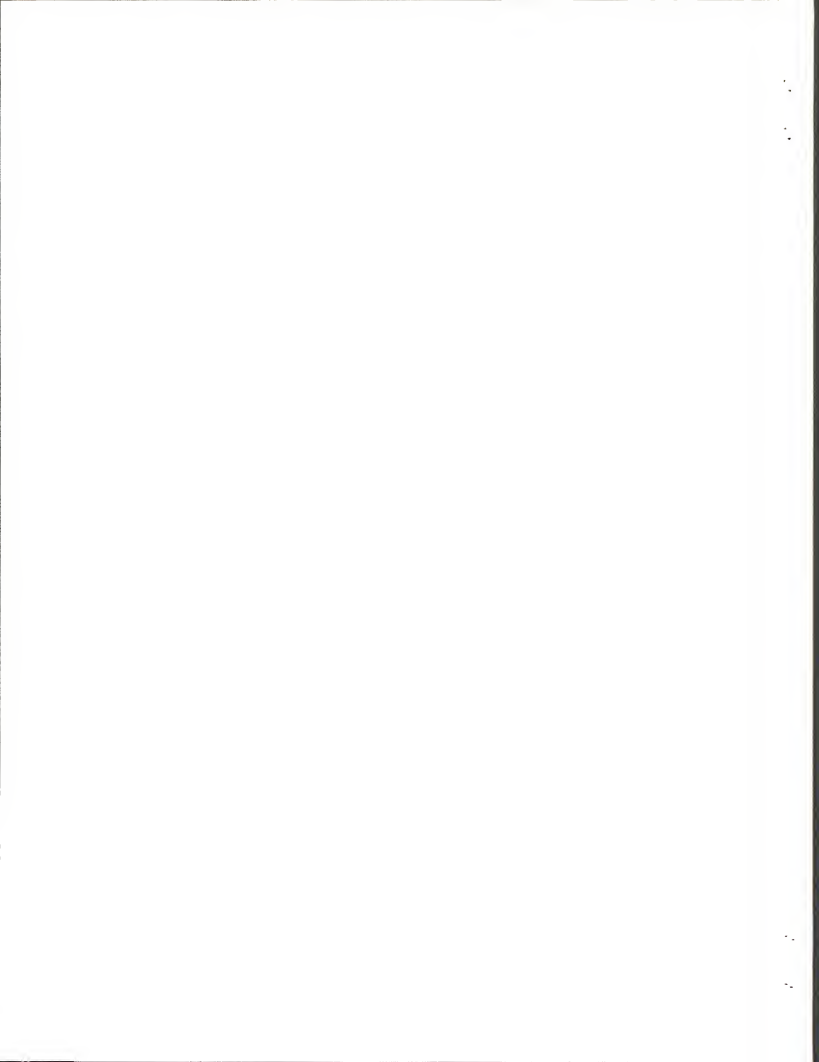


TABLE 7. MARSHALL DATA  
(50 Blow)

Gradation	5.5%				6.0%				6.5%			
	Stability	Density	Voids	VMA	Stability	Density	Voids	VMA	Stability	Density	Voids	VMA
1A	1825	2.280	6.8	16.7	1575	2.292	5.4	16.6	1814	2.304	3.9	16.6
2A	1625	2.345	4.0	14.3	1707	2.342	3.4	14.8	2304	2.371	1.6	14.1
3A					*	*	*		*	*	*	
					1613	2.325	4.3	15.4	1599	2.331	3.4	15.6
4A									*	*	*	
									1788	2.311	4.1	16.3
5A									1525	2.283	5.4	17.3
6A									1344	2.297	4.9	16.8
7A					1600	2.283	6.1	16.9	1688	2.306	4.5	16.5
8A					1450	2.286	6.0	16.8	1475	2.299	4.8	16.8

\* Interpolated data

#### Observations

This table was written to compare the voids and mixture properties of bituminous mixtures produced using the 8 initial gradations (Table 6) with the same gradations adjusted to have 4% -200M aggregate. This table shows the results of less -200M are inconsistent. Some gradations show no change in voids or Marshall properties while others are altered by as much as 1.9% voids. Reducing the % -200M does not always increase the amount of voids in bituminous mixture.



TABLE 8. MARSHALL DATA  
(75 Blow)

Gradation	5.5%				6.0%				6.5%			
	Stability	Density	Voids	VMA	Stability	Density	Voids	VMA	Stability	Density	Voids	VMA
1	2011	2.328	4.9	14.9	2427	2.371	2.1	13.7	2253	2.375	0.9	14.0
2	1846	2.368	3.0	13.4	1898	2.375	2.1	13.6				
3	1742	2.329	4.8	14.9	1759	2.355	3.1	14.3	2054	2.363	2.1	14.4
4									1699	2.313	3.9	16.2
5					2089	2.346	3.5	14.7	2047	2.342	3.0	15.2
6					2288	2.350	3.4	14.5	1976	2.343	2.9	15.2
7	1884	2.314	5.6	15.4	1977	2.328	4.3	15.3	2045	2.366	2.0	14.3
8	2377	2.335	4.7	14.6	2328	2.351	3.3	14.5				

### Observations

Comparisons within the table shows similarities of physical properties can occur with bituminous mixtures using different gradations. The gradations that yielded comparable bituminous mixtures with 75 blow compaction were gradations 5 and 6. Compaction levels can be very significant in defining the properties of bituminous mixtures. You will recall that Gradations 4 and 5 produced similar bituminous mixtures with 50-blow compaction.



TABLE 9. MARSHALL DATA  
(75 Blow)

Gradation	5.5%				6.0%				6.5%			
	Stability	Density	Voids	VMA	Stability	Density	Voids	VMA	Stability	Density	Voids	VMA
	*	*	*		*	*	*					
1A	1933	2.302	5.9	15.9	1954	2.315	4.4	15.8				
2A	1846	2.356	3.5	13.9	2262	2.368	2.4	13.9				
3A	1698	2.331	4.7	14.8	1898	2.354	3.1	14.4	2275	2.363	2.1	14.4
4A									*	*	*	
									1836	2.328	3.4	15.7
5A	1850	2.308	5.6	15.6	1450	2.297	5.5	16.4	1711	2.328	3.6	15.7
6A	1840	2.308	5.8	15.6	1785	2.309	5.1	16.0	1891	2.326	3.6	15.8
					*	*	*		*	*	*	
7A					1988	2.318	4.8	15.7	2098	2.328	3.6	15.7
8A	2050	2.305	5.9	15.7	2028	2.316	4.8	15.7	1976	2.336	3.2	15.4

\* Interpolated Data

#### Observations

Using 75-blow compaction with aggregate gradations containing 4% -200M aggregate produced an equalizing effect. Mixtures 4A - 8A are so nearly equal the standard deviation of mixes would obscure the differences. This uniformity of mixture properties with different gradations was not as noticeable using 50-blow Marshall compaction.

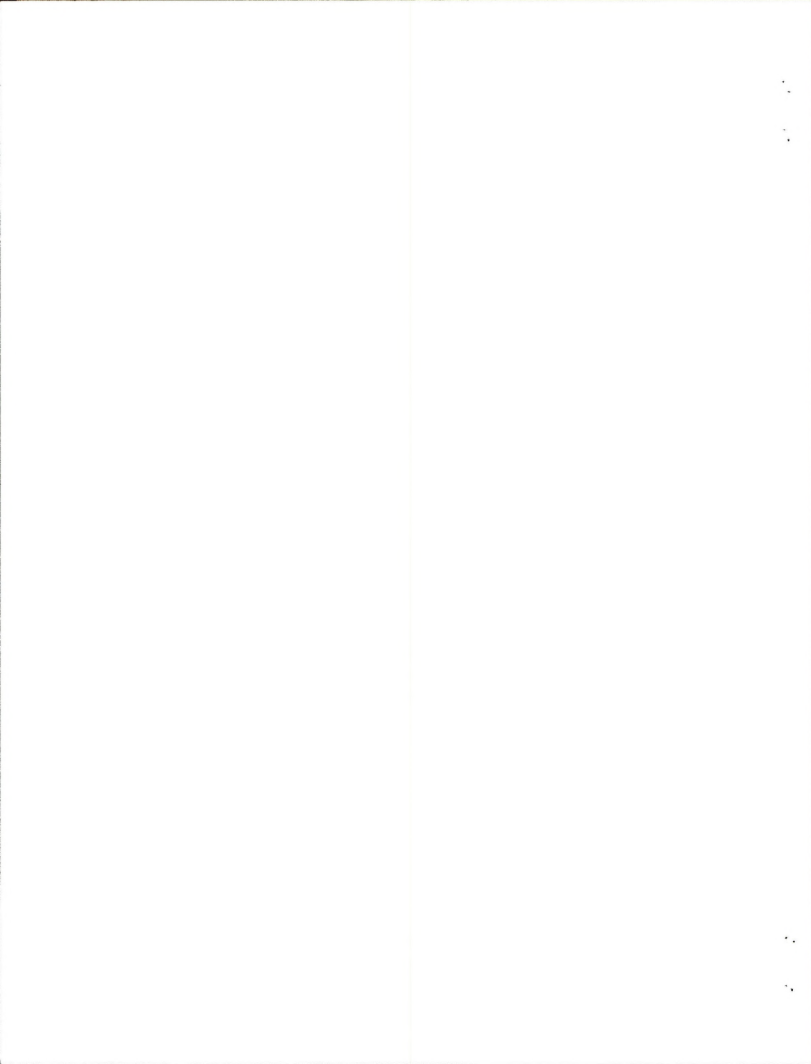


TABLE 10. MARSHALL DATA (ADDITIVES)  
(50 Blow)

ORIGINAL AC GRADATION	GRADE PROPERTIES	85-100 NONE*	120-150 NOVOPHALT	120-150 CARBON BLACK	120-150 3% LATEX	UNKNOWN AC20R
1	Asphalt Content	6.0	5.8	6.9	6.1	6.0
1	Stability	1911	2512	2094	1785	2374
1	Density	2.335	2.347	2.337	2.337	2.342
1	Flow	11	9	11	12	12
1	V.M.A.	15.0	14.6	15.9	15.2	15.0
1	Voids	3.6	3.5	3.5	3.3	3.3
	Imm. Compression	83.0	70.5	62.2	83.9	83.0
	Dry Strength	280.1	366.1	309.6	296.0	319.9
	Wet Strength	232.4	257.9	192.6	248.3	265.8
3	Asphalt Content	6.3	5.9	6.8	6.0	6.0
3	Stability	1498	2132	1664	1716	1677
3	Density	2.327	2.350	2.341	2.346	2.333
3	Flow	12	10	10	10	11
3	V.M.A.	15.6	14.6	15.6	14.8	15.3
3	Voids	3.5	3.5	3.5	3.5	3.3
	Imm. Compression	85.8	78.0	85.8	96.0	79.8
	Dry Strength	229.2	331.9	224.4	277.7	300.0
	Wet Strength	196.6	258.7	192.6	266.6	239.5
6	Asphalt Content	6.9	6.9	7.5	6.5	6.75
6	Stability	1615	1850	1567	1714	1733
6	Density	2.317	2.316	2.313	2.328	2.322
6	Flow	9	9	9	9	11
6	V.M.A.	16.4	16.6	17.2	15.9	16.3
6	Voids	3.5	3.5	3.6	3.6	3.5
	Imm. Comp Ratio	68.1	87.8	81.8	95.8	100.0
	Dry Strength					
	Wet Strength					

#### Observations

All data was determined with Marshall specimens containing voids standardized at 3.5% with a maximum deviation of +0.1%, -0.2%. Samples prepared with 120-150 AC base asphalt and the additives Novophalt, Carbon Black, or 3% Latex were compared to an 85-100 AC control with no additive. AC 20R as furnished by Asphalt Supply was similarly compared. Novophalt maintained the asphalt demand of the control mixture or required 0.2 - 0.4% less asphalt. Carbon Black increased the AC demand a maximum of 0.9% and a minimum of 0.5%. Adding 3% latex to asphalt tended to decrease the asphalt demand. AC 20R maintained the asphalt demand at the same level as unmodified asphalt.

Marshall stabilities with gradations 1 and 3 increased 600 pounds with Novophalt while using gradation 6 increased only 200 pounds. Carbon Black yielded stabilities equal to or slightly higher than the control mixture as did 3% latex. AC 20R yielded stabilities 100 - 450 psi higher than the control mixture. VMAs and immersion compression ratios were comparable or increased with all additives.

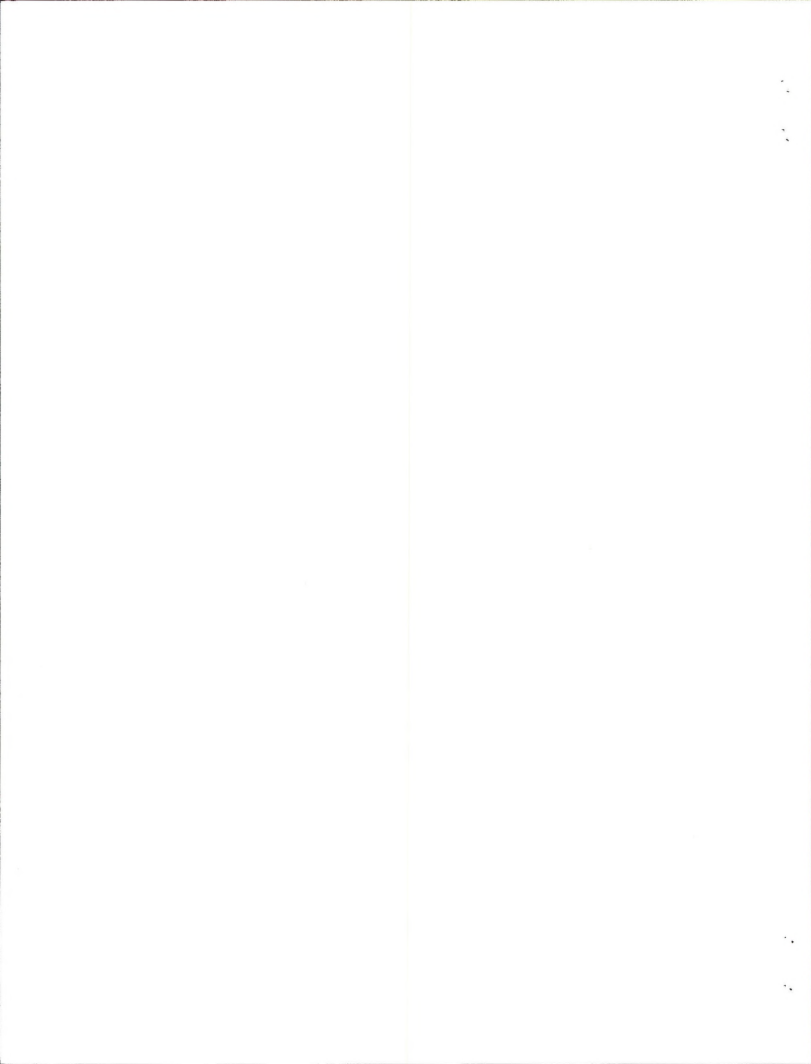
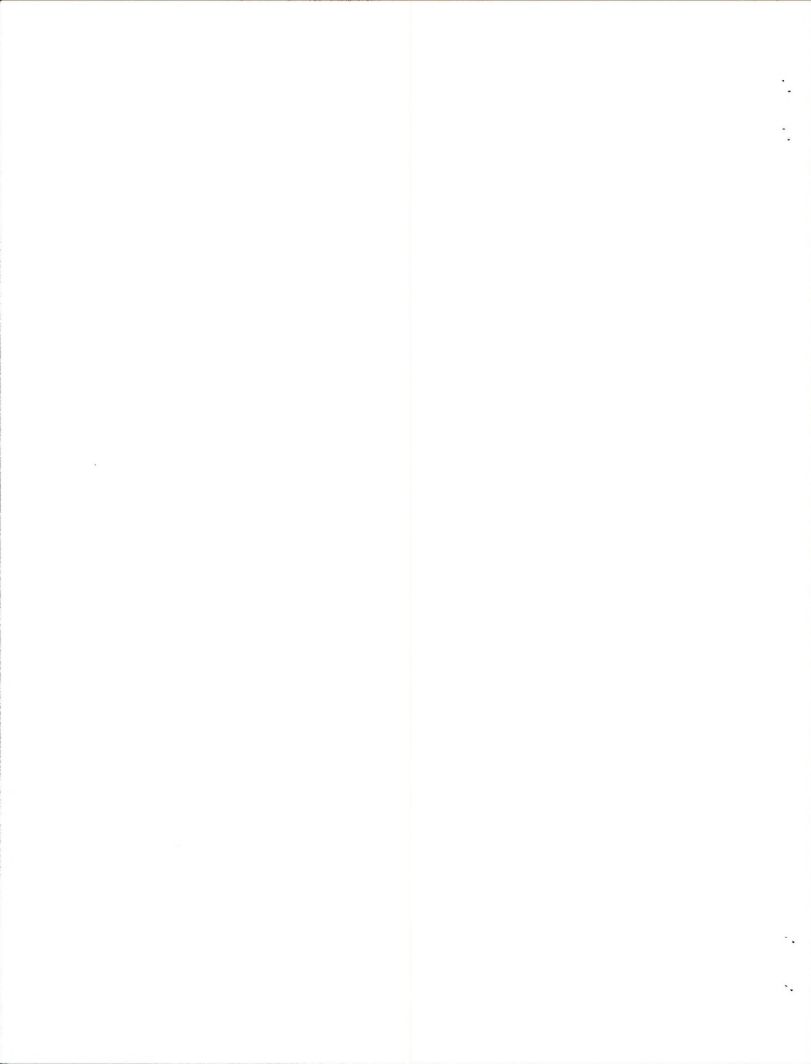


TABLE 11. MARSHALL DATA (ADDITIVES)  
(75 Blow)

<u>GRADATION</u>	<u>PROPERTIES</u>	<u>NONE</u>	<u>NOVOPHALT</u>	<u>CARBON BLACK</u>	<u>3% LATEX</u>	<u>AC-20R</u>
1	Asphalt Content	5.75	5.4	6.15	5.75	5.5
	Stability	2219	3249	2805	2509	2970
	Voids	3.5	3.5	3.5	3.6	3.3
	Density	2.350	2.367	2.360	2.346	2.366
	Flow	10	11	10	11	12
	V.M.A.	14.3	13.6	14.3	14.6	13.7
	Voids	3.5	3.4	3.6	3.6	3.3
	Imm. Compression	81.5	88.5	79.2	67.0	84.3
	Dry Strength	296.0	269.0	214.9	296.8	273.0
	Wet Strength	241.1	238.0	170.3	198.9	230.0
3	Asphalt Content	5.90	5.5	6.05	5.65	5.5
	Stability	1750	2444	2422	2181	2348
	Voids	3.5	3.6	3.5	3.5	3.6
	Density	2.342	2.359	2.357	2.355	2.343
	Flow	9	9	9	10	11
	V.M.A.	14.7	13.9	14.3	14.2	14.5
	Voids	3.5	3.6	3.6	3.5	3.6
	Imm. Compression	72.0	87.0	78.6	89.7	91.5
	Dry Strength	233.2	226.9	171.1	208.5	214.9
	Wet Strength	167.9	197.4	134.5	187.0	196.9
6	Asphalt Content	6.0	6.25	6.60	6.25	6.0
	Stability	2288	2704	2569	2236	2516
	Voids	3.4	3.2	3.5	3.5	3.5
	Density	2.350	2.345	2.330	2.339	2.347
	Flow	9	11	9	9	10
	V.M.A.	14.5	15.0	15.7	15.3	14.8
	Voids	3.5	3.2	3.6	3.5	3.5
	Imm. Comp. Ratio	59.1	93.7	76.0	94.1	79.8
	Dry Strength	292.0	263.4	162.3	215.7	279.4
	Wet Strength	172.6	246.7	123.3	202.9	222.9

Observations

Asphalt demand for Marshall specimens containing additives was usually higher than the control Marshall using 85/100 AC by .25 - .33%. There were exceptions such as Novophalt with gradations 1 or 3 which required less asphalt. Immersion compression was noticeably improved in many instances. The higher binder content (asphalt and additive) and the resultant greater film thickness may have contributed to the improved immersion compression test results.



### Observations

TABLE 12  
50 Blow Compaction Results with Aggregate from Eckart Construction, Miles City.

The data in Table 12 was developed using aggregate from a second source. We obtained bituminous mixture test results from a second aggregate source to compare with data from the first source using the same gradation. The asphalts 85-100 AC and AC 20R were used as we tested the uniformity of bituminous mixture properties when the aggregate source was changed.

By this testing, the dependence of asphalt demand on aggregate gradation, and the recognition of gradation as a factor that influenced Marshall stability were confirmed. Mixtures using gradations 1, 3 and 6 yielded stabilities that were equivalent with data obtained using the first source of aggregate.

We did find some inconsistent behavior when testing using AC20R. With this aggregate, Marshall specimens containing AC 20R using gradations 3 and 6 produced stabilities an average of 400 psi less than similarly graded specimens made with 85-100 asphalt cement. This lowering of stabilities did not occur with the original source aggregate when AC 20R was used for the asphalt.

When Marshall specimens were fabricated using 60-70 pen AC, stabilities with gradation 1 increased 300 psi. The other tested gradations, 3 and 6 which are coarser, did not increase in stability when the harder asphalt was used.



TABLE 12. MARSHALL DATA  
(50 Blow)

<u>GRADATION</u>	<u>PROPERTIES</u>	<u>85/100</u>	<u>60/70</u>	<u>AC-20R</u>
1	Asphalt Content	5.7	5.8	6.0
	Stability	1910	2255	1900
	Voids	3.7	3.4	3.7
	Density	2.326	2.327	2.312
	Flow	9	10	11
	VMA	15.1	15.2	15.9
	Imm. Comp. Ratio	70.0	95.6	105.5
	Dry Strength	275.3	305.5	272.9
	Wet Strength	192.6	292.0	288.0
3	Asphalt Content	6.0	6.0	6.3
	Stability	1928	1800	1565
	Voids	3.2	3.3	3.5
	Density	2.327	2.322	2.305
	Flow	10	9	12
	VMA	15.3	15.5	16.3
	Imm. Comp. Ratio	81.5	102.0	94.6
	Dry Strength	198.2	245.8	220.4
	Wet Strength	161.5	250.6	208.4
6	Asphalt Content	6.0	6.5	6.5
	Stability	1447	1546	1284
	Voids	4.7	3.4	3.2
	Density	2.292	2.305	2.308
	Flow	9	9	12
	VMA	16.6	16.5	16.4
	Imm. Comp. Ratio	81.4	102.3	98.8
	Dry Strength	205.3	241.0	205.3
	Wet Strength	167.1	246.6	202.9

NOTE: Aggregate Source - Eckart Construction, Miles City, MT

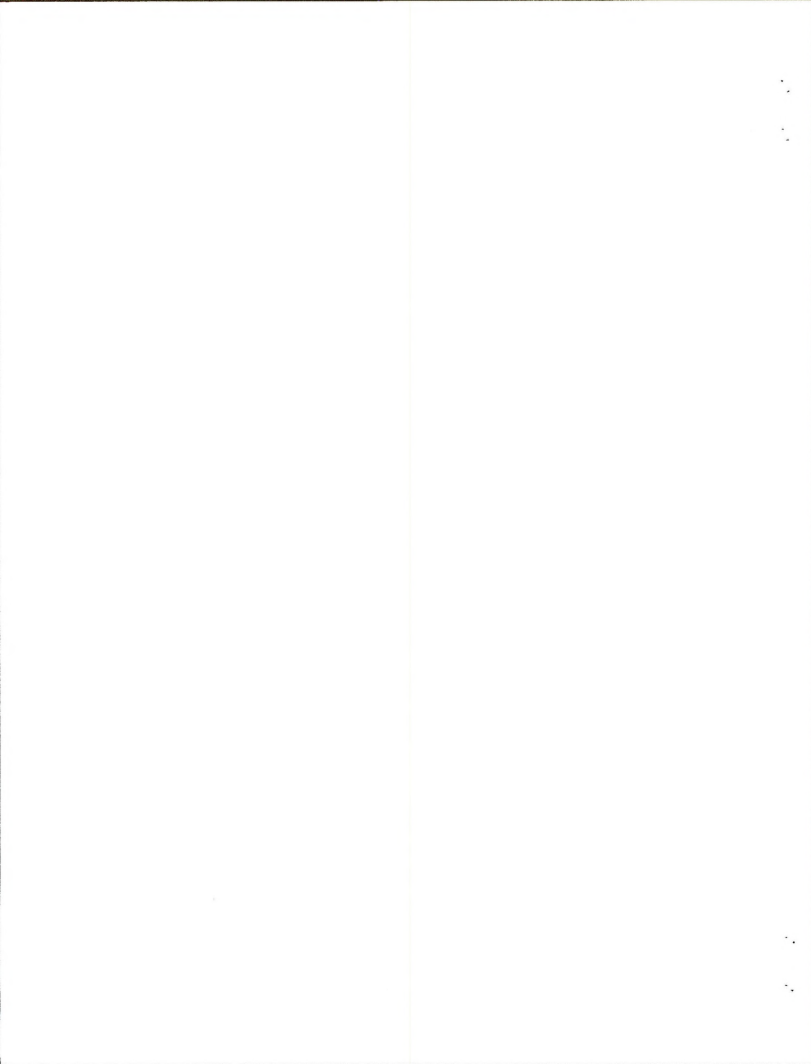


TABLE 13 MARSHALL DATA  
(75 Blow)

<u>GRADATION</u>	<u>PROPERTIES</u>	<u>85/100</u>	<u>60/70</u>	<u>AC-20R</u>
1	Asphalt Content	5.6	5.65	5.5
	Stability	2272	2128	1938
	Voids	3.6	3.5	3.7
	Density	2.331	2.330	2.330
	Flow	10	9	8
	VMA	14.9	14.9	14.8
	Imm. Comp. Ratio	69.6	87.6	91.7
	Dry Strength	267.4	269.0	239.5
	Wet Strength	186.2	235.6	219.6
3	Asphalt Content	5.8	5.75	6.0
	Stability	1803	1713	1350
	Voids	3.5	3.4	3.5
	Density	2.327	2.306	2.317
	Flow	9	9	8
	VMA	15.2	15.9	15.7
	Imm. Comp. Ratio	90.0	89.0	88.2
	Dry Strength	197.4	253.1	209.3
	Wet Strength	178.3	225.2	184.6
6	Asphalt Content	6.4	6.3	6.3
	Stability	1880	1597	1379
	Voids	3.4	3.6	3.5
	Density	2.325	2.306	2.309
	Flow	10	9	9
	VMA	15.7	16.3	16.2
	Imm. Comp. Ratio	92.9	90.2	85.2
	Dry Strength	200.5	234.8	209.3
	Wet Strength	186.2	211.7	178.3

Observations

The use of 75 blow compaction using aggregate from the Eckart source produced the same voids relationships as observed using the first source of aggregate. The AC 20R increased the stability of the mixture using gradation 1 but reduced stability 300 pounds with gradations 3 and 6. The reduction of stability using AC 20R seems to be an individual behavior characteristic of this aggregate. Seventy-five blow Marshall compaction with AC20R did not increase the stabilities significantly. This also is a behavior that seems unique to this aggregate source.



## ABSON TEST RESULTS

TABLE 14. ORIGINAL ASPHALT PROPERTIES

MATERIAL	PEN	VISCOSITY @ 275°F	PVN	LOH
85/100 Exxon	79	345 cSt	-0.706	0.01%
85/100 Conoco	85	258 cSt	-1.062	0.19%
120/150 Exxon w/Novophalt	53	718 cSt	-0.089	0.04%
120/150 Exxon w/Carbon Black	83	397 cSt	-0.445	0.16%
120/150 Exxon w/Latex	102	1109 cSt	+1.377	0.08%
Asphalt Supply Ac-20R	100	764 cSt	-0.744	0.13%
60/70 Conoco	63	292 cSt	-1.169	0.13%

TABLE 15. EXTRACTED ASPHALT PROPERTIES

MATERIAL	PEN	DUCTILITY @ 40°F	VISCOSITY @275°F	TOUGHNESS & TENACITY	SOFTENING POINT
85/100 Exxon	71	6.75 cms.	372 cSt	44.67 in-lbs 8.87 in-lbs	122°F
85/100 Conoco	56	5.75 cms.	328 cSt	26.03 in-lbs 3.58 in-lbs	124°F
120/150 Exxon w/Novophalt	71	6.0 cms.	435 cSt	41.67 in-lbs 10.12 in-lbs	124°F
120/150 Exxon w/Carbon Black	154	100.5 cms.	3460 cSt	19.53 in-lbs 4.32 in-lbs	143°F
120/150 Exxon w/Latex	71	53.0 cms.	914 cSt	37.82 in-lbs 7.59 in-lbs	131°F
Asphalt Supply AC 20-R	69	32.25 cms.	989 cSt	100.86 in-lbs 136.93 in-lbs	133°F
60/70 Conoco	44	0.25 cms.	383 cSt	96.15 in-lbs 6.07 in-lbs	133°F

### Observations

Physical properties of the asphalts used in the rutting study were determined from virgin and extracted asphalt. Refer to Tables 14 and 15. The results were similar except viscosity of the extracted carbon black asphalt increased significantly compared to the original asphalt.

Based on the extracted asphalt, using the carbon black additive produced the highest 40°F cold temperature ductility; 100 cm at 40°F. The 275°F viscosity was also the highest, as was the softening point of 143°F. The 143°F softening point is more than 20° higher than that of the base asphalt.

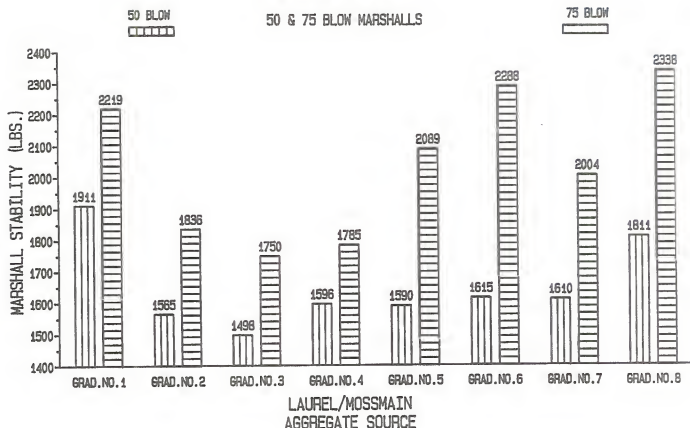
The AC 20R had the best toughness and tenacity and the second lowest 275°F viscosity.

The unmodified 60-70 AC was brittle at reduced temperatures stretching only .25 cm before it failed.



# MARSHALL STABILITY

## MONTANA DEPARTMENT OF HIGHWAYS MATERIALS BUREAU RUTTING STUDY MARSHALL STABILITY



### Gradations 1-8

#### Figure 1

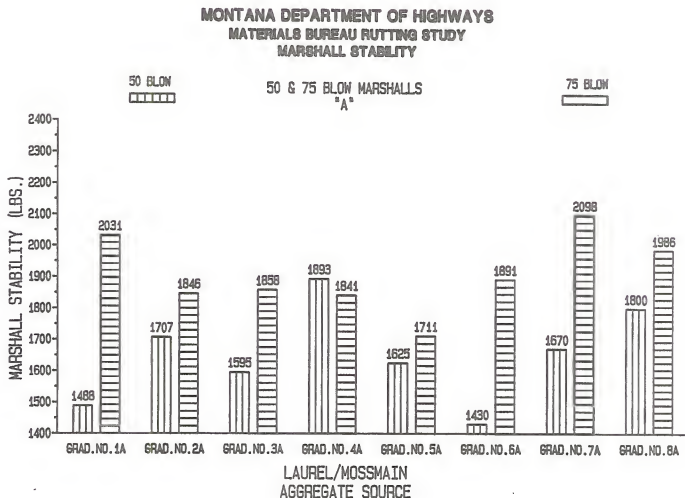
#### 50 Blow Marshall compaction

It may be seen that gradation 1 had the highest stability with 50 blow compaction; gradation 8 also had high stability. Figure 2 shows that gradations 2-7 had essentially equal stabilities averaging about 200 lbs. less than those obtained with gradations 1 and 8.

#### 75 Blow Marshall compaction

Figure 1 also shows the influence of the 75 blow compaction. Some of the gradations responded to increased compactive effort more than others although all of the stabilities increased by at least 300 pounds.





#### 50 Blow Marshall compaction

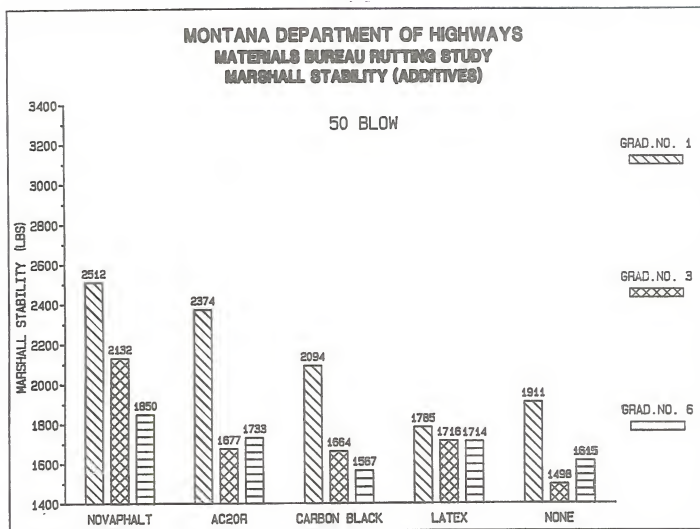
Gradation 1A is identical to gradation 1 except that the %200M is reduced to 4%. Notice the reduction of Marshall stability that occurs in bituminous mixtures with 1A gradation. This shows the importance of %200M in some aggregate matrices. Using gradations 5A, 7A, and 8A produced the least change in Marshall stability of the bituminous mixtures evaluated when the percent %200 M was reduced to 4%. Compare Marshall stabilities to those obtained using gradations 5, 7, and 8 respectively.

#### 75 Blow Marshall compaction

The Marshall stability of these gradations also tended to increase with 75 blow compaction. Stabilities were as much as 600 lbs. higher although the typical increase was 200-300 lbs.



Gradations 1, 3, and 6 with Additives  
Figure 3



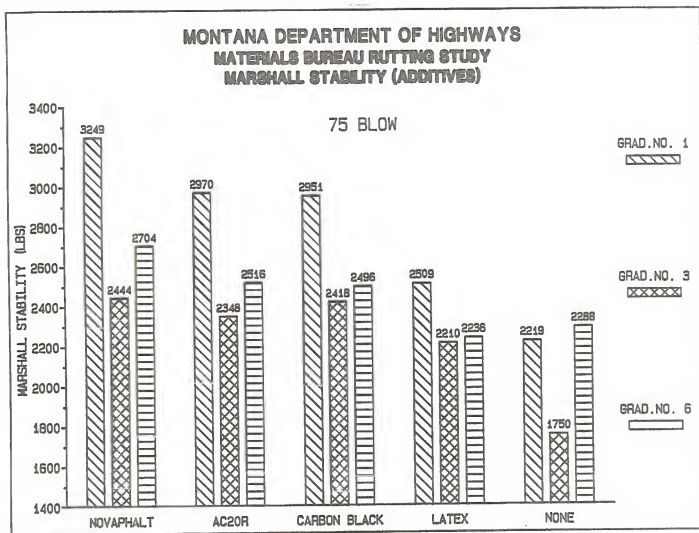
#### 50 Blow Marshall data

Mixtures containing Novophalt, AC 20R, Carbon Black and Latex were tested using gradations 1, 3, and 6 to evaluate various additives. The mixes made with Novophalt had the highest Marshall stability for all three gradations.

Notice that using different gradations can produce different bituminous mixture properties using the same aggregate asphalt and additive. Notice also that the additive can produce a major change of bituminous mixture properties with the same aggregate and gradations.



Figure 4  
75 Blow Marshall data



The stabilities of bituminous mixtures containing additives was increased by 500-600 lbs. by using 75 blow compaction. Gradation also influences the stability of the bituminous mix. Marshalls made with gradation 3 averaged less stability than Marshalls made with either gradation 1 or 6.

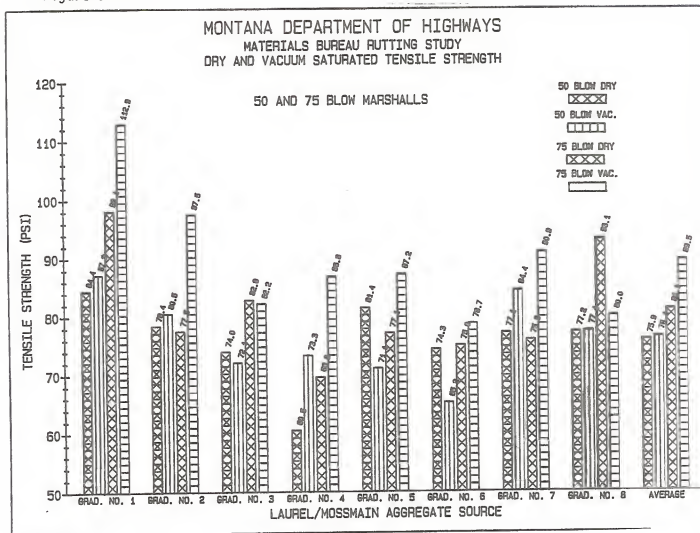
Mixes made with Novophalt had the highest Marshall stability for all three gradations tested using 75 blow Marshall compaction. You will recall Novophalt mixtures also exhibited the highest stability of the 50 blow Marshall compaction samples tested.



# TENSILE STRENGTH

Gradations 1-8

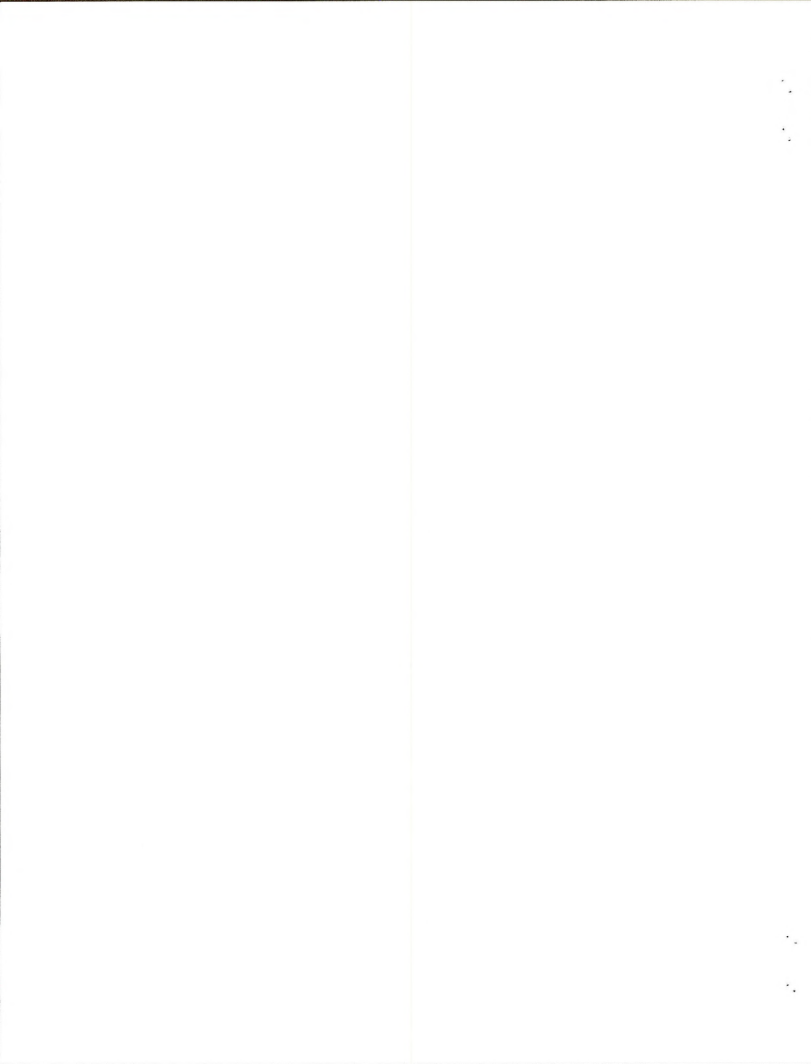
Figure 5



## 50 Blow and 75 Blow Compaction

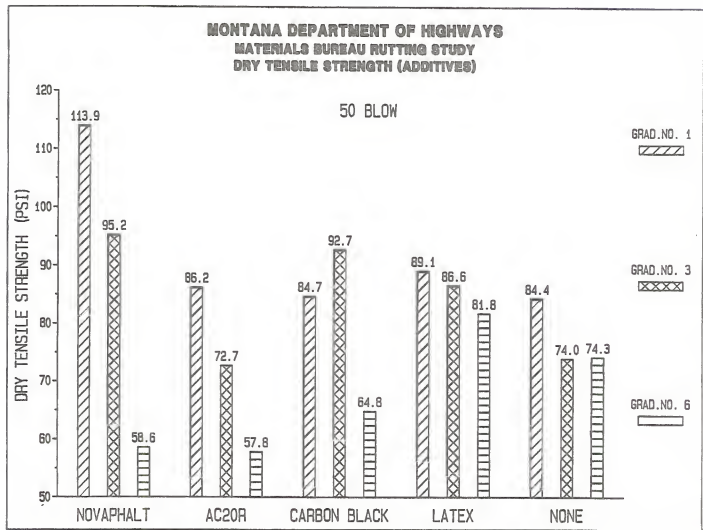
Bituminized aggregate mixture with different gradations was evaluated for indirect tensile strength. Specimens made at the optimum asphalt content for each gradation were tested for dry and wet strength. The tensile strengths of specimens made using the 50 blow compaction and 75 blow compaction are both shown on this graph.

Tensile strength was dependent upon gradation. Dry tensile strengths may be compared to each other, vacuum saturated tensile strengths may also be compared to each other. It is not valid to compare vacuum saturated specimen tensile strengths to dry specimen tensile strengths because of a procedural error. In the final stages of testing it was determined the dry specimens were not "cured" in the 55°F air bath long enough to obtain 55°F. The vacuum saturated specimens immersed in 55°F did reach 55°F temperature equilibrium. This difference caused the testing as conducted on the dry specimens with asphalt that was less viscous than intended. The dry strengths of the samples are less by an indeterminate amount than they actually should be. After the first set of specimens, those shown on Figure 5, this error was corrected. Strength ratios of dry and saturated specimens may be meaningfully evaluated for subsequent sets of samples.



DRY TENSILE STRENGTH WITH ADDITIVES  
(Temperature of specimens 55°F corrected)

Figure 6  
50 Blow Compaction

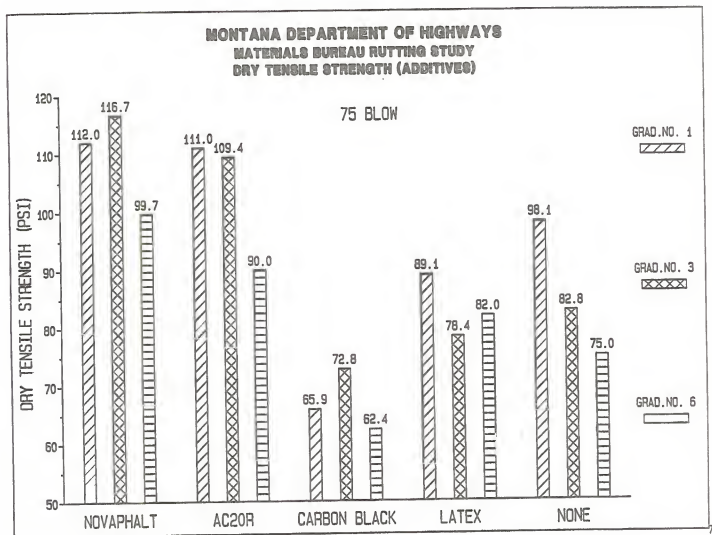


The samples with the highest tensile strength with additives was dependent upon gradation. Gradation 1 with additives had the highest dry tensile strength except using the carbon black. Gradation 6 was markedly inferior with each additive tested compared to other gradations.



# DRY TENSILE STRENGTH WITH ADDITIVES

Figure 7  
75 Blow Compaction

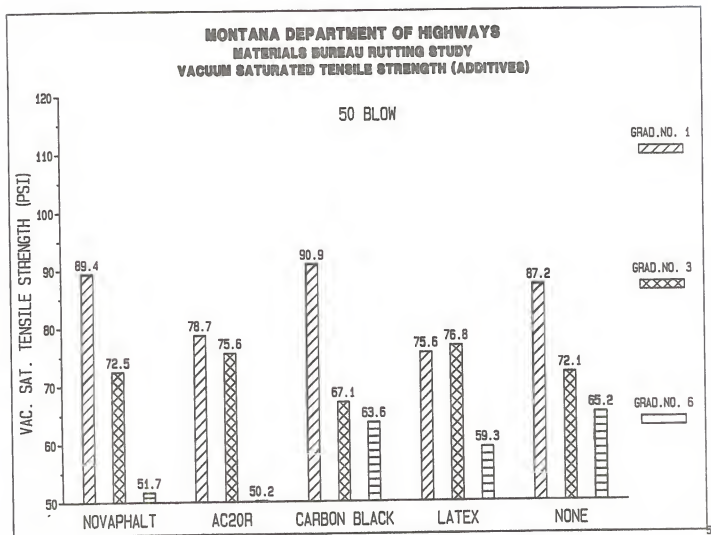


Bituminous mixture dry tensile strength with 75 blow compaction increased compared to 50 blow compaction except using carbon black or latex. Mixtures with AC 20R were improved by at least 25 psi for all three of the gradations tested with the source 1 aggregate. Mixes made from gradation 6 developed 7-20 psi less tensile strength than the other gradations on the graph.

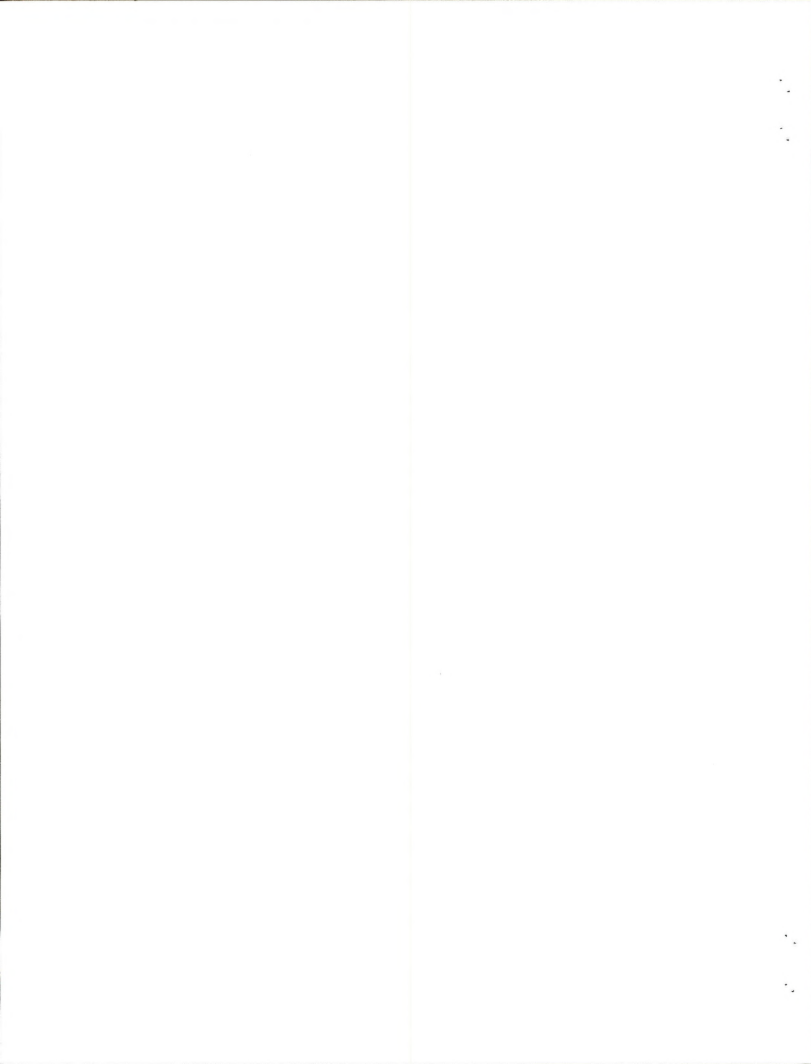


# VACUUM SATURATED TENSILE STRENGTH WITH ADDITIVES

Figure 8  
50 Blow Compaction

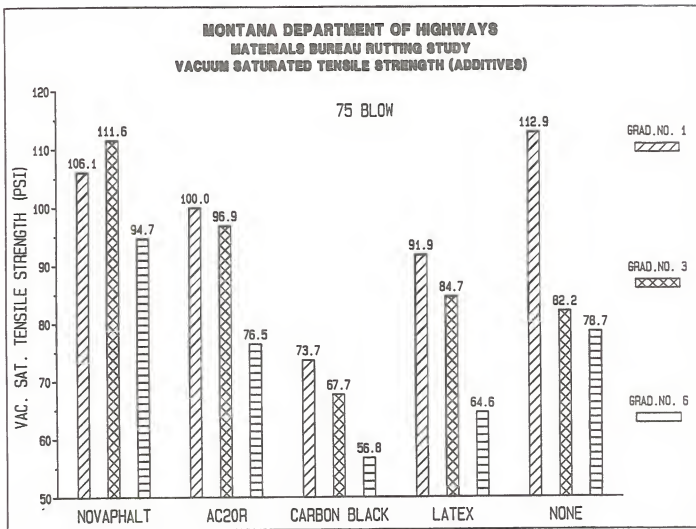


Tensile strengths of vacuum saturated bituminous mixtures with additives were approximately equal to the vacuum saturated tensile strength of the bituminous mixtures with no additives. The gradation 1 vacuum saturated specimens had higher tensile strengths than were obtained with the other gradations.



VACUUM SATURATED TENSILE STRENGTH WITH ADDITIVES

Figure 9  
75 Blow Compaction



The vacuum saturated tensile strengths of 75 blow compaction specimens showed a difference with gradation. Gradation 1 continued to show the greatest tensile strength. Gradation 3 was used to develop higher tensile strengths than could be developed using gradation 6.



# Rutting Study Summary of Tensile Strength Test Results

## RUTTING STUDY TENSILE STRENGTH TEST RESULTS

Number	Vacuum Saturated Tensile Strength	Dry Tensile Strength	Wet/Dry Ratio	Number	Vacuum Saturated Tensile Strength	Dry Tensile Strength	Wet/Dry Ratio
50 Blow 1	87.2	84.4	1.03	50 Blow 1A	56.9	67.3	0.84
50 Blow 2	80.5	78.4	1.03	50 Blow 2A	69.9	73.1	0.96
50 Blow 3	72.1	74.0	0.97	50 Blow 3A	74.3	71.0	1.05
50 Blow 4	73.3	60.5	1.21	50 Blow 4A	60.8	71.8	0.85
50 Blow 5	71.1	81.4	0.87	50 Blow 5A	77.4	70.9	1.09
50 Blow 6	65.2	74.3	0.88	50 Blow 6A	67.0	66.1	1.01
50 Blow 7	84.4	77.1	1.09	50 Blow 7A	80.8	56.3	1.4
50 Blow 8	77.4	77.2	1.00	50 Blow 8A	71.0	56.4	1.26
Average	76.4	75.9	1.01	Average	69.8	66.6	1.06
Standard Deviation	7.4	7.1	0.1	Standard Deviation	8.1	6.7	0.2
75 Blow 1	112.9	98.1	1.15	75 Blow 1A	80.8	93.1	0.87
75 Blow 2	97.5	77.5	1.26	75 Blow 2A	108.5	89.1	1.22
75 Blow 3	82.2	82.8	1.00	75 Blow 3A	99.1	77.8	1.27
75 Blow 4	86.8	69.6	1.25	75 Blow 4A	86.5	88.4	0.98
75 Blow 5	87.2	77.1	1.13	75 Blow 5A	84.7	88.7	0.95
75 Blow 6	78.7	75.0	1.05	75 Blow 6A	78.9	78.7	1.00
75 Blow 7	90.9	75.9	1.20	75 Blow 7A	86.6	73.1	1.20
75 Blow 8	80.0	93.1	0.86	75 Blow 8A	102.2	80.8	1.26
Average	89.5	81.1	1.1	Average	90.9	83.7	1.09
Standard Deviation	11.2	9.7	0.1	Standard Deviation	10.9	7.0	0.2

HWsk:249E

Comparing the tensile strengths of the No. 1 - No. 8 specimens with the 1A-8A specimens containing 4% -200 M, the tensile strengths of the group 1A-8A specimens had an average of 10 psi less tensile strength. 75 blow Marshall compaction increased the A group specimen tensile strengths more than it did for other sets of samples. As a result the vacuum saturated tensile strengths of both groups using 75 blow Marshall compaction was approximately 90 psi.

Mixes made from gradation No. 1 had higher tensile strength than mixes made with gradation No. 3 or No. 6 with or without additives. This was especially obvious for specimens made using the 50 blow Marshall compaction.



### Creep Compliance

Creep testing with the bituminous mixtures was performed to further evaluate the physical properties of plant mix. The testing was performed at 73°F and 140°F test temperatures. A fixed load which is standardized for different test temperatures was applied to a Marshall test specimen. The deformation that occurred from the load was recorded at time intervals of 5, 10, 100, 500, 1000, and 4,000 seconds.

Creep compliance is calculated from the following equation:

$$\text{Creep Compliance } D(t) = \frac{E_y(t)}{T_y}$$

Wherein  $E_y = Y_{T_y}[0.148] = \text{Strain}$

$T_y$  = vertical deformation at time T (inches)

$T_y$  = stress

$T_y$  is obtained from a linear graph of load (lbs.) vs. pressure (psi)<sup>-1</sup>. By recording the load used, the corresponding stress (psi)<sup>-1</sup> can be determined.

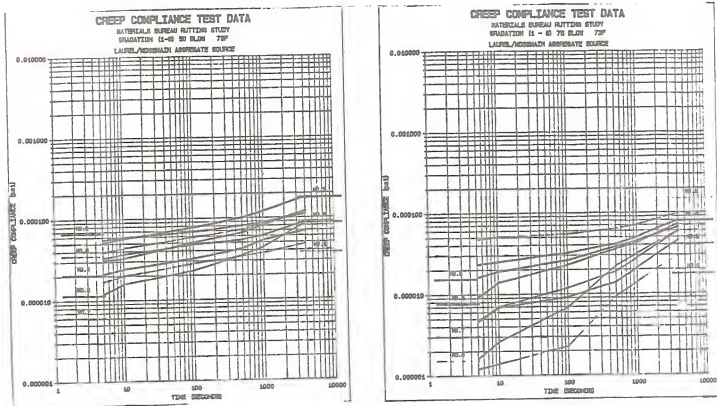
The creep data with the bituminous mixtures was plotted as a graph of deformation vs time (refer to figures 11 and 12). Since field data is not available to correlate performance with this parameter, it assumed less creep is desirable. Creep testing was performed at 140°F and 73°F. When we determined that temperature control at the higher temperature was unstable, we did not report data obtained using the 140°F test temperature.

Creep testing of bituminous mixes was performed with Marshall specimens constructed with aggregate from the Laurel/Mossmain pit source, lab No. 584279-80. Several different gradations, 50 and 75 blow compaction and different additives were evaluated.



### Creep Compliance

Figure 10 - Samples 1-8, 50 Blow Compaction versus 75 Blow Compaction 73°F

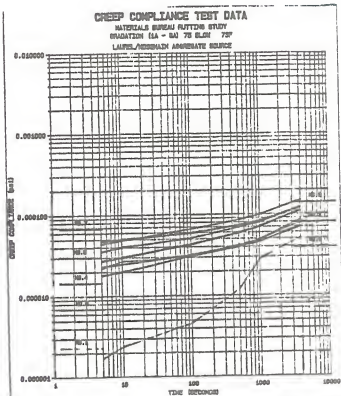
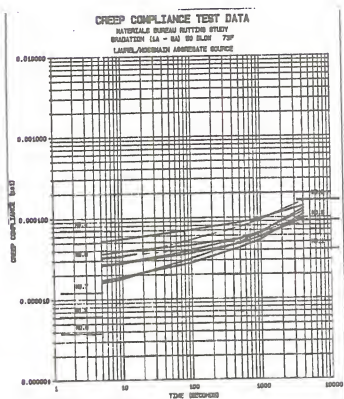


- A) Samples produced using 75 blow Marshall compaction had less overall creep compliance than specimens produced using 50 blow Marshall compaction, especially during the shorter time intervals.
- B) Specimens made using Gradation No. 1 had the lowest creep compliance values of the gradations tested using 50 blow compaction at the 4000 second time interval.
- C) When samples were made using 75 blow compaction, the samples made using Gradation No. 8 had the lowest creep compliance values at the 4000 second time interval.

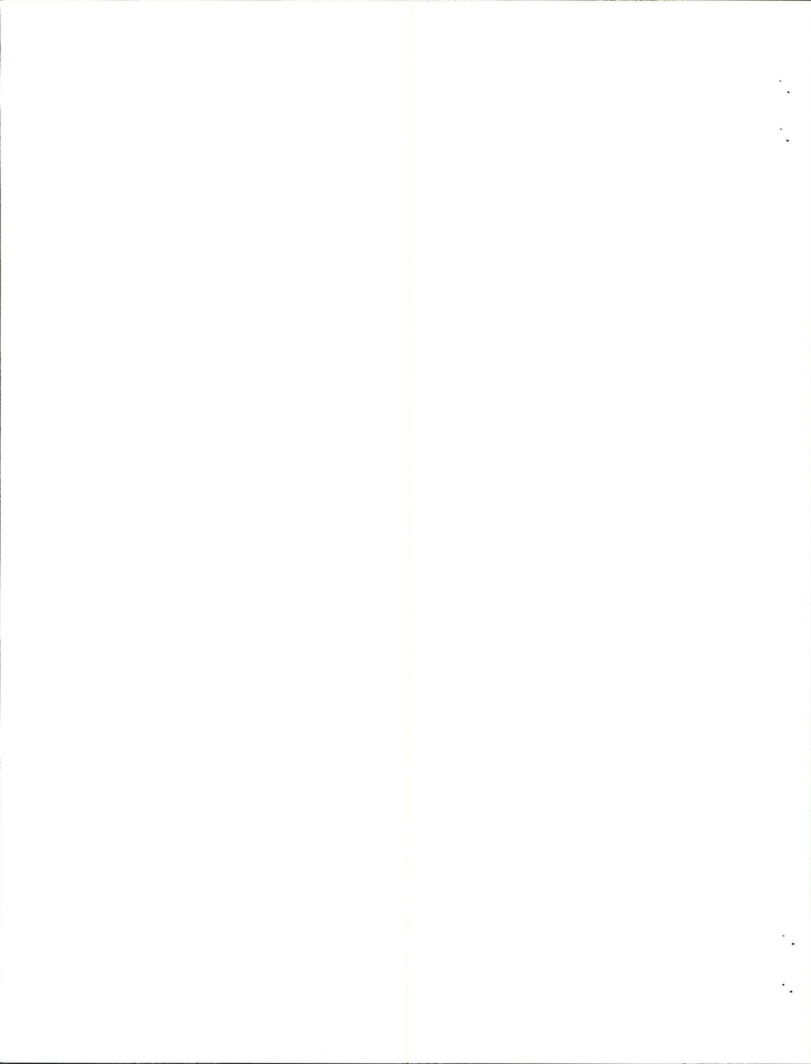


### Creep Compliance

Figure 11 - 1A-8A, 50 Blow Compaction versus 75 Blow Compaction 73°F

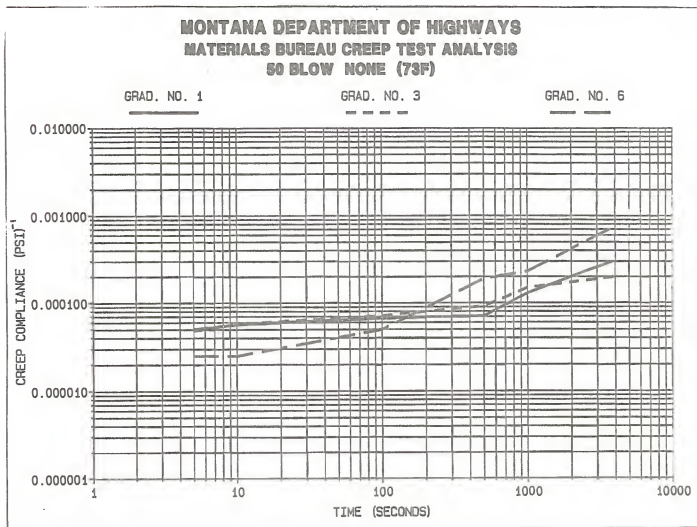


- A) Samples produced using 75 blow Marshall compaction had less overall creep compliance than samples produced using 50 blow Marshall compaction.
- B) Samples produced using Gradation No. 1A had the lowest 4000 second creep compliance values of the specimens tested at 73°F using 50 blow Marshall compaction. When samples were produced using 75 blow compaction, Gradation 1A again developed the lowest creep compliance at the 4000 second interval.

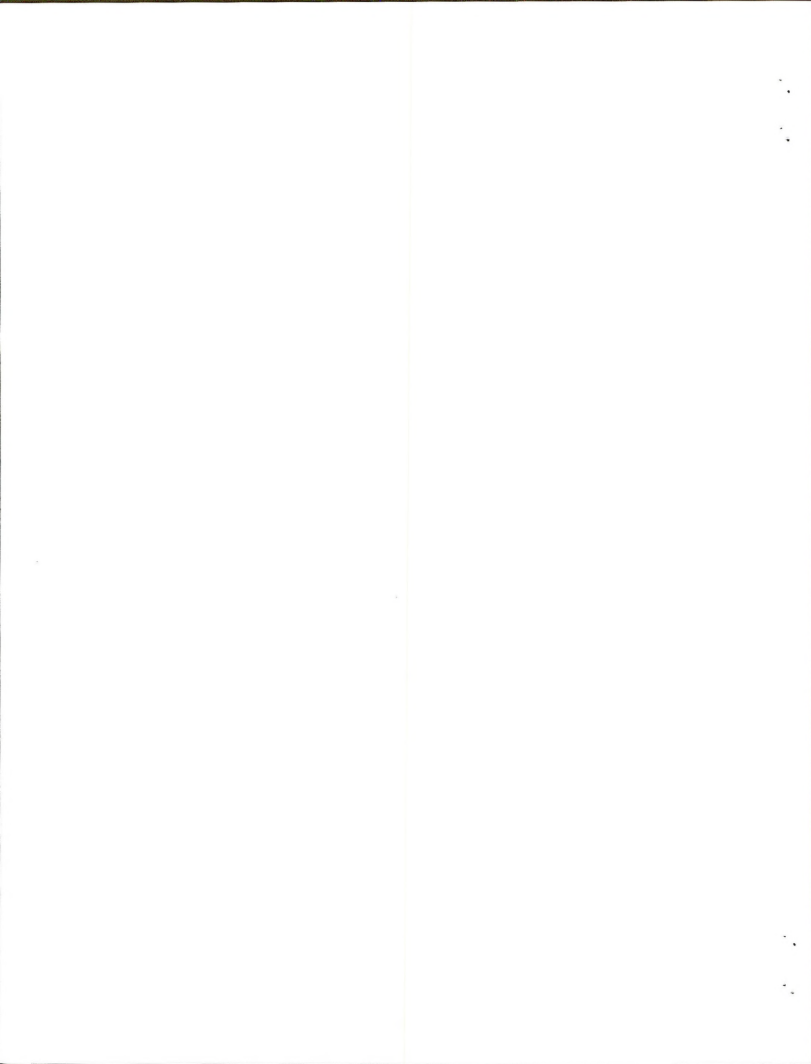


Creep Compliance Testing With No Additives

Figure 12 - 50-Blow Marshall Compaction 73°F

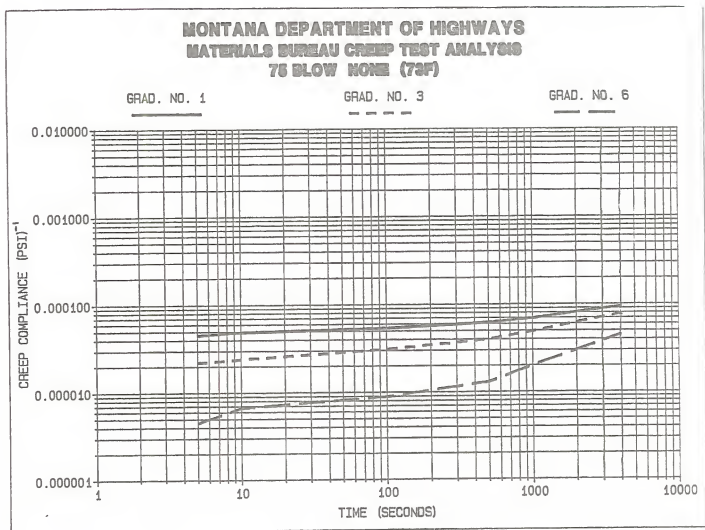


The creep data was similar for the different gradations tested that were produced using 50 blow Marshall compaction. Few differences were noted regardless of gradation or additive at the 4000 second interval.



Creep Compliance Testing With No Additives

Figure 13 - 75-Blow Marshall Compaction 73°F

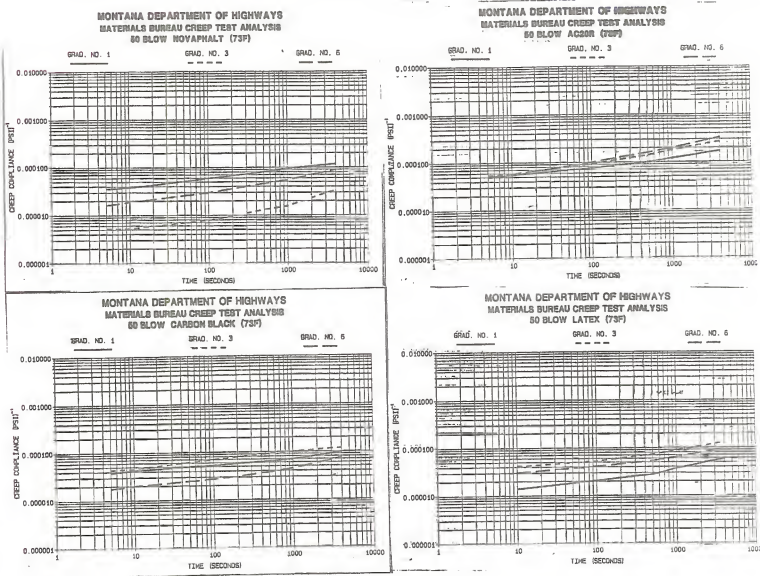


Using seventy-five blow Marshall compaction did not substantially change the 4000 second creep compliance results compared to creep with 50 blow compaction. Creep at the earlier time intervals was significantly different and thus the rate at which the specimens developed creep varied with gradation when 75 blow Marshall compaction had been used.



## Creep Compliance Testing With Additives

Figure 14 - 50-Blow Marshall Compaction 73°F

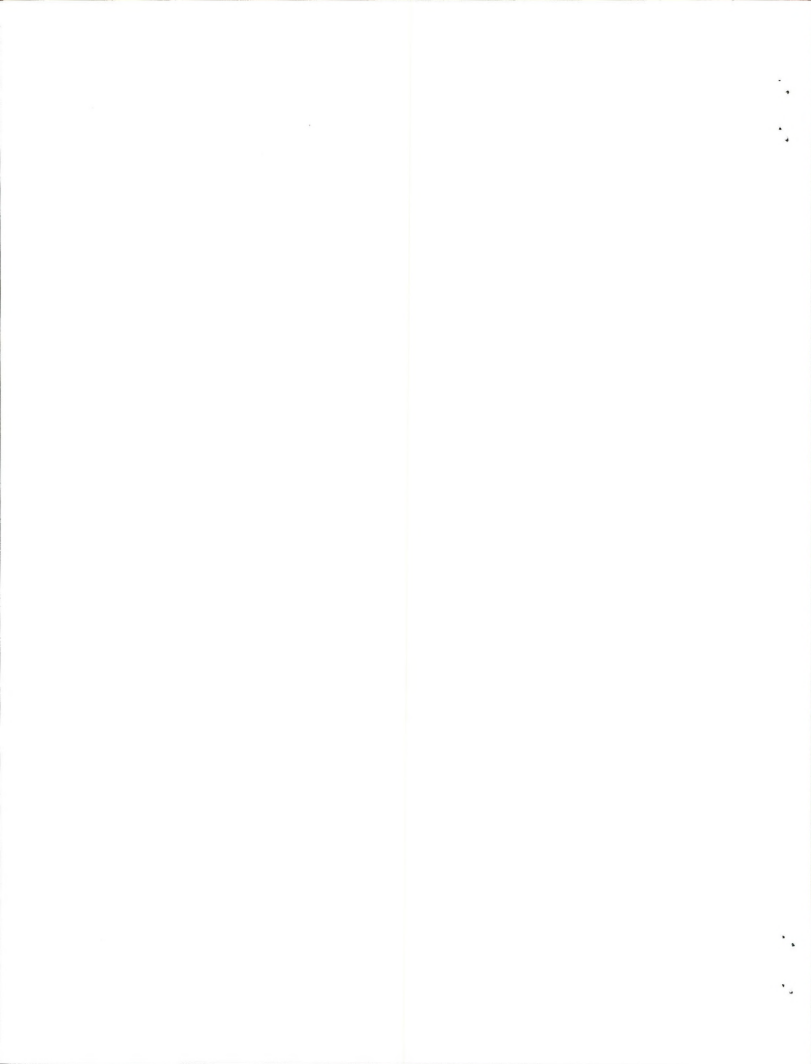


The creep compliance of all the 50-blow specimen sets varied with gradation and additive.

In general, creep was less than that obtained with the same gradation without an additive.

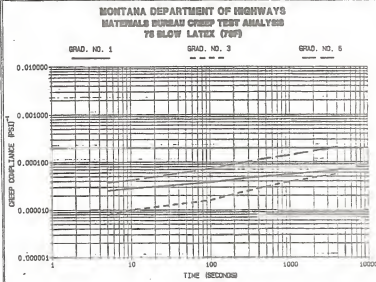
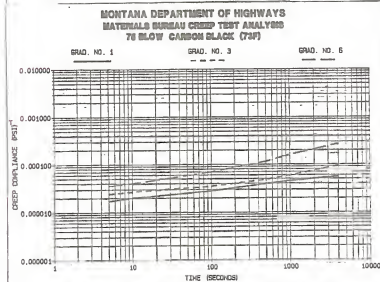
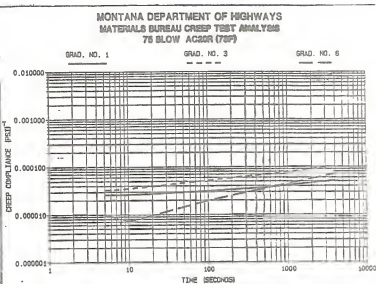
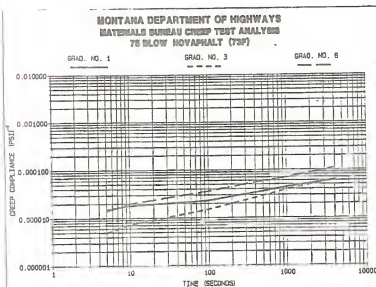
None of the creep plots with additives changed relative position when compared by gradation, regardless of the time interval studied. The range of creep at 4000 seconds was between .000015 and .00014, a change by a factor of 10.

The creep with Novophalt using gradation 1 was higher than with the other gradations. This was a reversal of a trend in which using gradation 1 yielded either the lowest creep or creep which approached the lowest values recorded with the other additives.

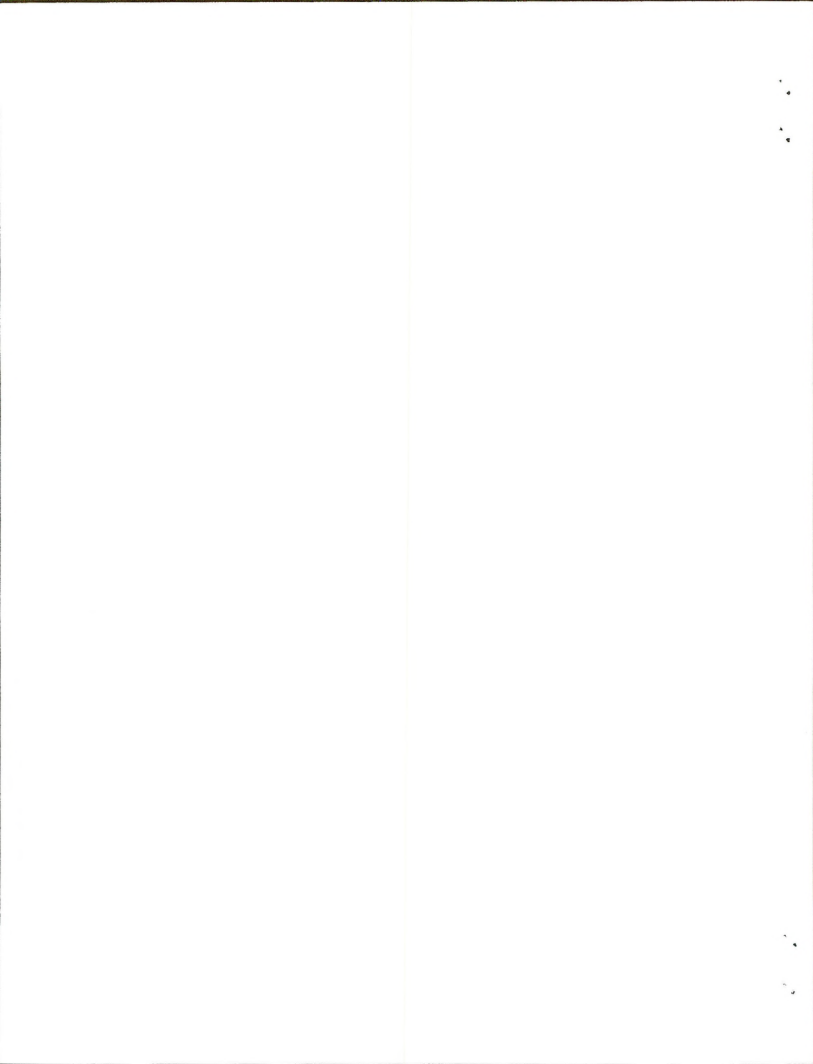


## Creep Compliance Testing With Additives

75-Blow Marshall Compaction 73°F

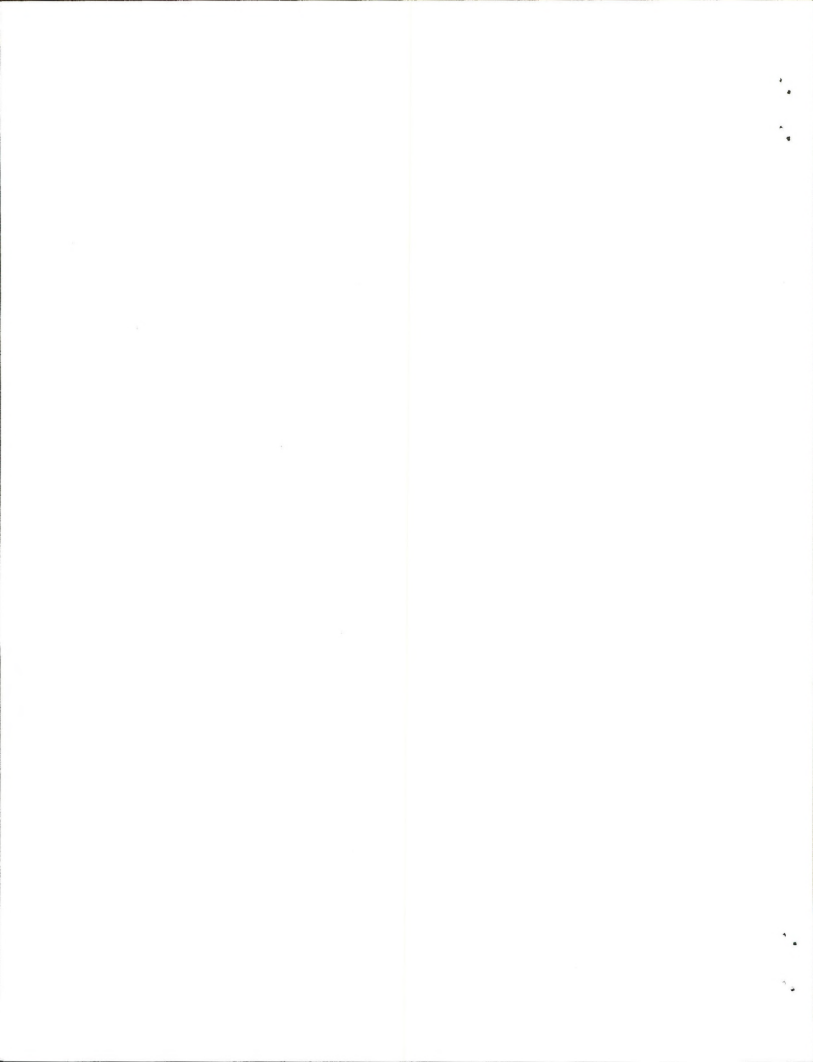


Gradation 1 usually yielded the lowest creep. Gradation 6 usually produced the highest creep. Gradation 3 was erratic; sometimes it had the lowest creep, sometimes the highest creep and sometimes it was the average data. The creep samples with additives were not always better than that of the control samples without the additive.



## Conclusions

1. It was learned that the properties of Marshall specimens are highly dependent upon gradation. There were large differences in stability and asphalt demand with gradation as the variable.
2. Increasing Marshall compaction from 50 blow to 75 blow increased stability approximately 300 pounds per specimen and decreased asphalt demand an average of 0.5%.
3. Reducing the percentage of -200 M material increased the asphalt demand of mixtures by amounts ranging from 0.1% to 1.0%. This indicates a more complex arrangement exists than a simple replacement of asphalt by the fine aggregate.
4. Comparing Marshall properties using gradations 1-8 to 1A-8A show reductions of -200 M material increased mixture voids an average of 0.7% using the same asphalt content. However, less -200 M did not necessarily increase the VMA. Several mixtures and their counterpart mixtures with less -200 M had virtually the same VMA at the same asphalt percentage.
5. VMA and voids are not totally dependent upon each other. A mixture may have voids less than 2% and still have a VMA of 14-15.0%.
6. Tensile strength increased when compactive effort was increased. Tensile strength was also dependent upon the amount of -200 M aggregate, especially when using 50 blow Marshall compaction.
7. The testing was done to assess the influence of the gradation of the aggregate. When we conducted tests of bituminous mixture using a second aggregate source, but the same gradation, we obtained very similar data. We concluded that changing the aggregate source did not change the asphalt demand or mixture properties appreciably for the asphalt aggregate mixtures compared using Gradations 1, 3, and 6.
8. With some gradations the additives AC 20R, Novophalt and carbon black significantly improved properties of the mixtures. No single additive was always superior for every gradation.
9. The 60-70 pen AC and AC 20R were tested with the second aggregate source. Neither asphalt changed asphalt demand or raised Marshall stability consistently compared to the original mixture. With the Echert source aggregate, gradation 1 yielded 300 pounds more Marshall instability using 60-70 pen AC. This was one of the few systems that increased the stability with this aggregate source compared to 50-blow compaction and 85-100 AC.
10. Marshall stability did not increase with the Eckart source using AC 20R and 75 blow compaction. This is a major difference between the Laurel aggregate and the Miles City aggregate.
11. Creep compliance was clustered by the 4000 second interval for all 16 gradations evaluated. Creep compliance developed at different rates which may indicate a difference in rutting resistance.



12. Creep compliance with additives at 73°F, did not show large differences with gradations 1, 3, and 6, and 50 blow Marshall compaction compared to bituminous aggregate mixtures of these same gradations using 85-100 AC and no additives. 140°F creep compliance may be necessary to identify differences in bituminous mixtures.
13. Seventy-five blow Marshall compaction of creep specimens resulted in data that was more dependent upon gradation. Gradation 1 developed the lowest creep for three of the five additives tested with 75 blow compaction.
14. An overall analysis of the rutting study reveals that the optimum design of bituminous mixtures will vary considerably from one mix to another. Relationships between aggregate and asphalt combinations are complex; design of bituminous pavements requires numerous tests and trial mixes to fully determine the optimum combination of aggregate and asphalt for an individual bituminous pavement.

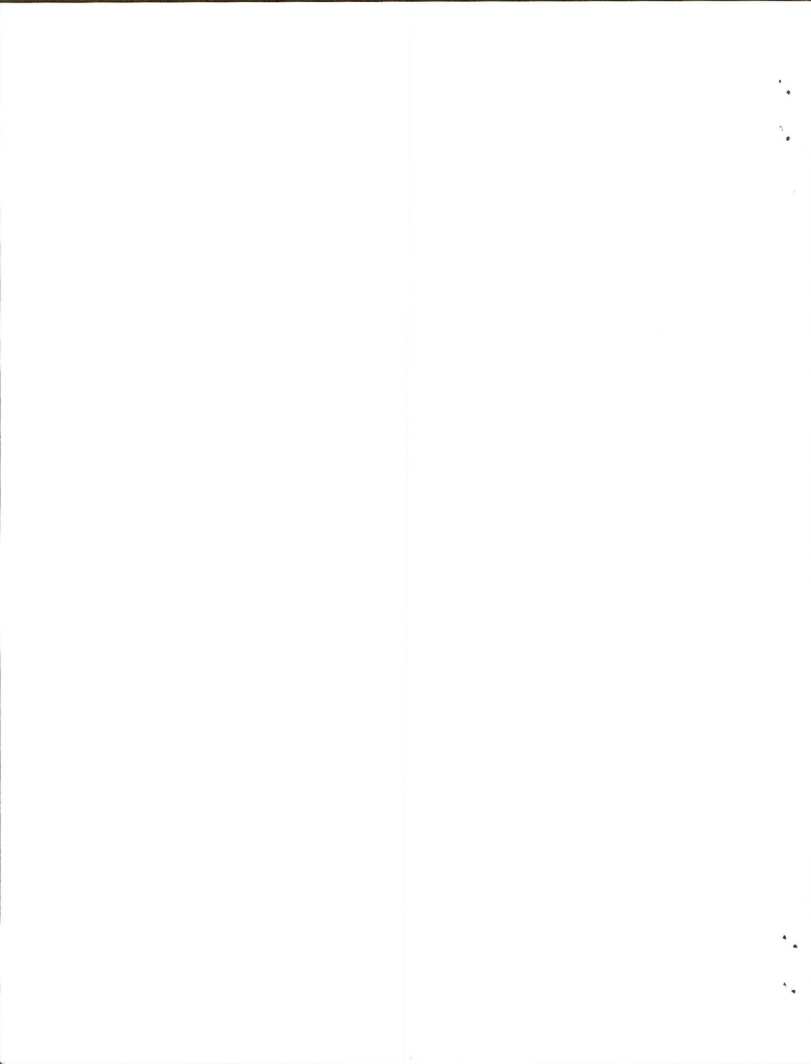
#### Recommendations

Gradation 1 was in many ways superior to the alternative gradations. Gradation 1 should be tested in an experimental pavement with non-absorptive aggregate. This gradation is very unusual. It is fine; 100% - 1/2 inch and contains 10% -200M crushed aggregate. The minimal absorption of the aggregate is probably what makes this gradation workable.

Based on increased stability, high asphalt softening point, and most consistent stabilities and tensile strengths with all of the gradations, Novophalt should be tested in a construction project.

Carbon black and rubberized asphalt sometimes increased stability, but were dependent on the gradation and aggregate source. The measured asphalt properties of viscosity and cold temperature ductility were increased significantly. Carbon black and rubberized asphalt should be seriously considered if the data supports their use after considering gradation and compatibility unique to the aggregate. Test sections or construction with these materials could often be justified.

More work needs to be done at developing aggregate gradation-voids relationships since we did not determine a system for obtaining VMA at a particular level during this investigation.





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